METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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METALLURGIA

THE BRITISH JOURNAL OF METALS.
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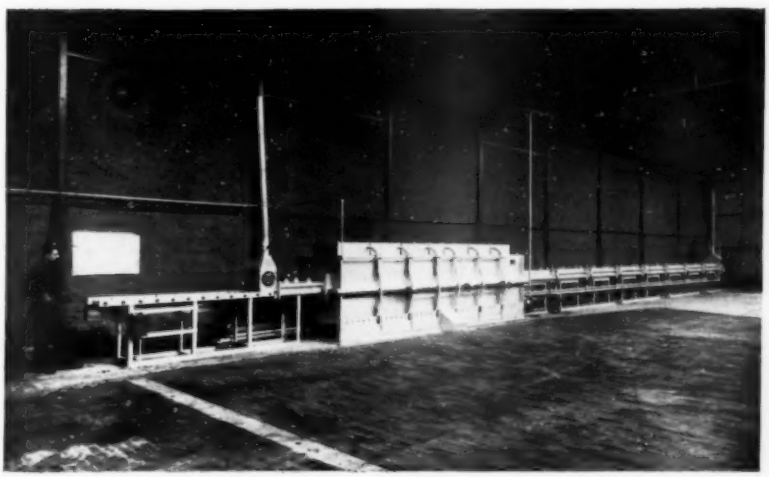
APRIL, 1936. VOL. XIII., No. 78.

A Continuous Bright Normalising Furnace for Hot- and Cold-rolled Steel Strip

Heat-treatment furnace design and operation have made rapid progress during recent years. Probably the most striking development in this field is the progress achieved in bright annealing as a result of atmosphere control, and in this article, the first electric furnace installed in this country for the continuous bright normalising of hot- and cold-rolled steel strip is described.



A view of the new continuous bright normalising furnace from the charging end.

IT is well known that heat influences the quality and cost of almost all manufactured products, but it is not always appreciated how many variable factors affect the conduct of heat-treating operations. Even with considerable knowledge of the heating phase of the process—and in present-day practice it would appear that increasing attention is being given to this part of heat-treatment—the importance of the cooling phase is not always realised; yet the uniformity and nature of the final adjustment of the structure of the material treated is determined in the cooling phase. Thus, to obtain a manufactured product of desired quality both the heating and cooling operations must be controlled as accurately as modern practice permits.

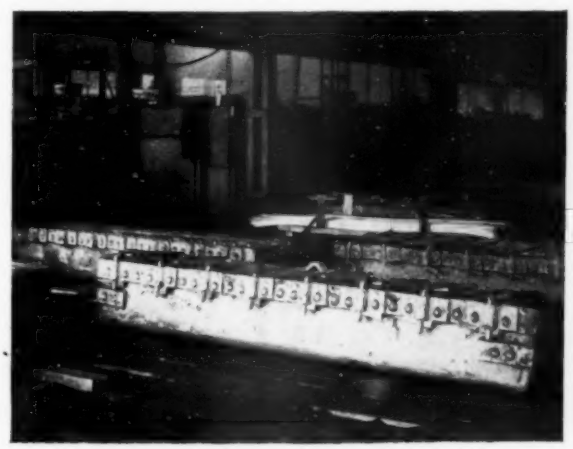
Probably the most striking development in heat-treatment practice is in the bright annealing of metals and alloys, in which various types of furnaces have been applied with remarkable results. Progress in this direction has been rapid. For this type of heat-treatment the control of the furnace atmosphere is as important as control of the temperature and, generally, this form of control is far more readily accomplished with electric furnaces than with fuel furnaces.

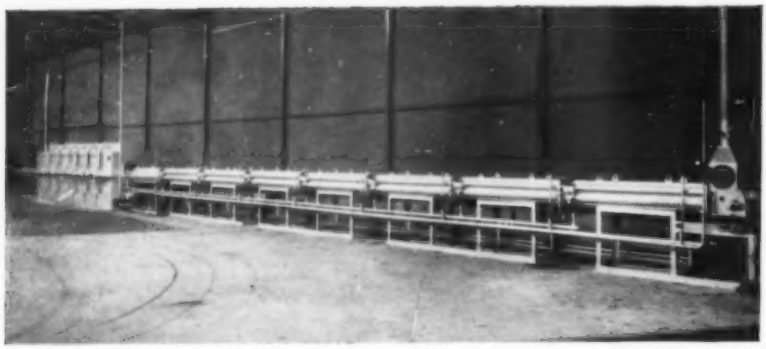
The bright annealing of some metals, particularly steel, has been common practice with fuel-fired furnaces for many years. This method has long been in use at the works of The Stourbridge Rolling Mills Ltd., for instance, for bright annealing cold-rolled steel strip, but the difficulty in obtaining uniformity of structure and bright surfaces by this method, with a reasonable degree of regularity, has caused the directors of this company to investigate recent developments in furnace design. In some cases the older method, which involves the use of boxes and packing, was successful in producing a clean unoxidised surface, in others it only reduced, and did not prevent, discolouration of the surface. Apart from the irregularity of results, the method necessitated heavy boxes, which made the process uneconomical, cumbersome and extremely slow.

As a result of a careful investigation, an electric furnace has been installed, and the directors are to be commended for their courage and foresight, particularly as this furnace is the first of its kind to operate commercially in the country. It is a continuous normalising furnace designed for a 12-in. maximum width of steel strip, and has an output capacity of approximately 6 cwt. per hour.

The equipment, which has been designed and constructed by Birmingham Electric Furnaces Ltd., comprises an

Packed boxes used in the older method of bright annealing.





The new furnace from the delivery end, showing the cooling chambers

electrically-heated furnace joined to a water-jacketed cooling chamber to form a continuous tunnel. The outer casing is made effectively gas-tight, and the end openings are restricted to a minimum required for the passage of the work. Closely-spaced rollers are arranged throughout the entire length of the equipment, including a loading table at the charging end. The rollers in the heating chambers are of nickel chromium alloy, these and the rollers in the cooling chamber being driven at a uniform surface speed by an electric motor through a variable-speed gear by means of which the rate of travel of the work can be controlled, according to thickness.

The heating elements, which are of heavy-gauge nickel-chromium strip, are supported in the roof and floor of the heating chamber, thus heating the steel strip uniformly on both sides. The elements are arranged in sections, each with independent temperature control, permitting the rate of heating to be graded through the furnace so that maximum output can be obtained. These elements are robust, and life of several years can be expected. Each section of elements is controlled by an automatic regulator which also serves as a temperature indicator. By this means the temperature is maintained constant at the desired value within a few degrees without any attention.

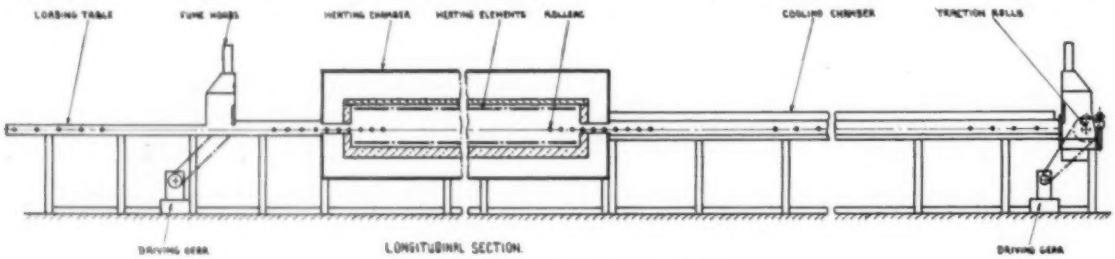
The furnace atmosphere is provided by a patented "Birlec" generator supplied with coal gas. This generator comprises a combustion chamber in which controlled quantities of coal-gas and air are burned. The resulting gases are passed through a purifying plant which removes water vapour and sulphur before admission to the furnace. The furnace atmosphere is slightly combustible, containing carbon monoxide, carbon dioxide, hydrogen and nitrogen, and as it has approximately three times the volume of the raw gas used, the cost of generating it, therefore, is relatively small.

The furnace is designed to deal with either coiled strip (this being drawn through the furnace in continuous length and recoiled at the discharge end), or straight lengths of strip, the closely-spaced roller hearth allowing very short lengths to be treated without difficulty, the range of gauge and width of material which can be handled in this installation being from 0·01 to 0·125 in. in thickness, and up to 12 in. in width. When dealing with narrow strips, a number can be passed through the furnace simultaneously, side by side, to make up the width capacity of the furnace, or, when normalising very thin strips, they can be handled in two or more thicknesses.

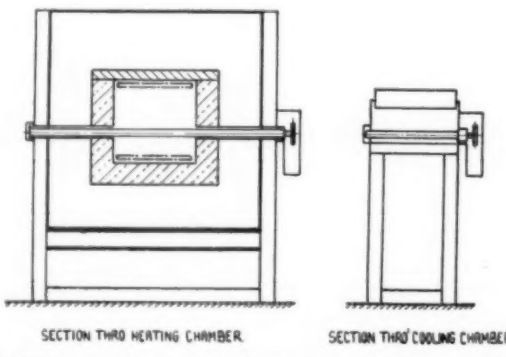
In view of the changed technique employed in the treatment of steel strip, The Stourbridge Rolling Mills Ltd., have housed this furnace in a new building, in which a second "Birlec" furnace of similar type, at present on order, is to be installed. This second furnace will have similar characteristics, but larger capacity – a maximum width of strip of 24 in. with an approximate output of 15 cwt. per hour. There are one or two interesting features about this new building which are worthy of mention here. It is built over the river Stour, with the remarkable result that strip enters the furnace in Worcestershire, and is delivered from the cooling chamber in Staffordshire. But probably the most noteworthy feature is that arrangements have been found necessary to heat the department during the winter; it is apparent therefore that during the hot summer as well as the winter, a reasonable degree of comfort may be assured for the workmen. This is surely unusual in a heat-treatment shop, and indicates how carefully these new furnaces are insulated.

The Normalising Process

Some confusion occasionally exists regarding annealing and normalising processes, and it may be mentioned here that annealing is concerned with the softening of steel and in relieving it of stresses and strains induced by working, but in addition to these results normalising requires the production of an entirely new crystalline structure, the constituents of which should be of the smallest grain size possible. This new structure is obtained at a temperature known as the upper critical range of the steel, *i.e.*, at the end point of the A 3 range. It is only at this temperature that there is a homogeneous austenite solution. The usual practice is to heat slightly above the upper critical range, whereas with ordinary annealing it is not necessary to raise the temperature to the critical range. To obtain complete refining of the grain the proper temperature is very important, but the exact temperature will depend upon the chemical composition, and more particularly upon the carbon content.



Diagrammic view of the furnace installation.

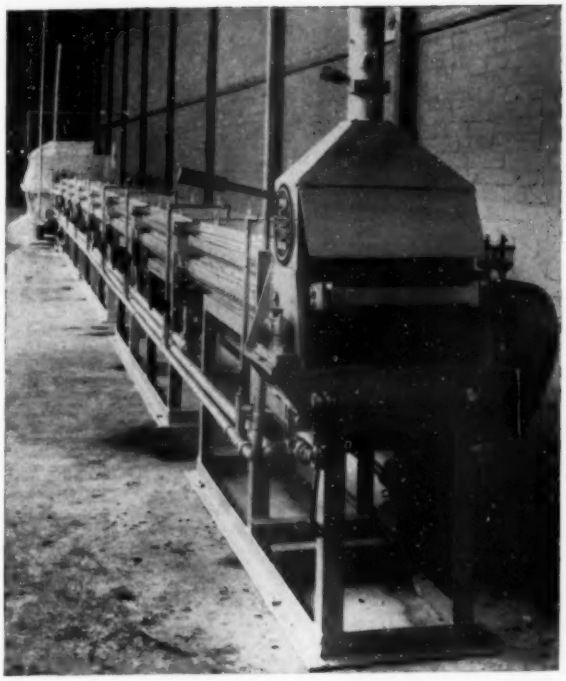


While the correct temperature is important, it is necessary that the steel be maintained at that temperature long enough to allow the formation of the new structure, and subsequently the cooling operation must maintain the fine structure obtained in the steel. Thus the design and operation of a continuous furnace for normalising strip steel must provide a suitable temperature, so that the steel will be uniformly heated, hold the steel at that temperature to permit of complete refining, and cool the steel rapidly to preserve the structure.

In this new furnace these important factors are under control, and sample pieces of a particular composition can be passed through the furnace and tested, the speed of the furnace being varied until the required temper is obtained, when continuous normalising of similar steel can proceed with complete assurance that the same results will be obtained as from the initial sample. The time-temperature cycle for any desired hardness or strength is thus readily determined, and can be reproduced accurately.

The advantages of normalising for deep drawing and pressing work are well known ; it gives the steel a higher Erichsen value than can be obtained by box annealing, although hardness tests may show higher figures, and this new continuous furnace seems to be ideal for ensuring strict uniformity of treatment, the elimination of grain growth, and, from an examination of Erichsen " cups " on strip treated in it, a fine grain structure.

It is well known that in the electric furnace the production of heat is independent of the atmosphere, and does not necessitate flues or other ventilation, so that the maintenance of an artificial atmosphere in the heating chamber and also in the cooling chamber is possible without the use of boxes or muffles. As a result of considerable development work the atmosphere can now be controlled to a remarkable degree of accuracy, and this continuous furnace is an excellent example of the great advances in bright annealing and normalising.



The delivery end of the furnace.

The writer wishes to express to Mr. Mitchell, Mr. Standish, Mr. Robinson and Mr. Berry, of The Stourbridge Rolling Mills Ltd., and to Mr. A. Glynne Lobley, of Birmingham Electric Furnaces Ltd., his sincere thanks for the opportunity of inspecting this electric furnace in operation.

1935 A.S.T.M. PROCEEDINGS*

THE Proceedings of the American Society for Testing Materials are published in two parts, Part I comprising committee reports and the new and revised A.S.T.M. standards. Part II gives all technical papers, including the Marburg Lecture. In view of the extensive work of this society, these volumes are very comprehensive.

Part I.—This contains 1,488 pages. Reports from 40 standing committees are included, and there are 136 tentative specifications either newly published or revised in 1935. In the section pertaining to ferrous metals, there are extensive reports covering standardisation and research on steel products, wrought and cast iron, corrosion, magnetic properties, iron-chromium and related alloys, fatigue and effect of temperature. Appended papers discuss fatigue tests on rotating beam machines and effect of long-time heating in impact strength of 18 : 8 steel.

The non-ferrous metal reports involve copper wire, corrosion, electrical-heating and resistance alloys, copper and alloys (cast and wrought), die-cast metals and screen-wire cloth. Extensive data are given on the widespread corrosion tests (atmospheric, liquid and galvanic) of non-ferrous metals and on the extensive exposure tests of die-cast metals. Other reports cover work on cement, brick, clay pipe, refractories, concrete, building units and concrete pipe. Appended papers discuss the relation of freezing and thawing resistance to physical properties of brick, specimens for mortar compression tests, and tests for volume changes in concrete.

Preservative coatings, petroleum products, road materials coal and coke, timber, waterproofing materials, electrical insulating materials, rubber products, textile materials, and water for industrial uses are subjects of other detailed reports ; also methods of testing, spectrographic analysis and metallography. Appended sections involve problems in standardizing methods of sampling water, microscopic method of particle size measurement and statistical methods of analysis and presentation of data.

Part II.—In addition to 37 technical papers presented at the 1935 annual meeting, this part gives the extensive written and oral discussion, thus providing various viewpoints on the respective subjects. It contains 769 pages, and includes the Marburg Lecture on " Aircraft : Materials and Testing."

The Symposium on Spectrographic Analysis comprises six technical papers describing methods in current use as applied to various materials—steel, platinum, magnesium and other non-ferrous materials, graphite electrodes, etc.

In the metals field there are numerous papers covering such topics as the following : Life of rear-axle gears, high-speed fatigue tests, influence of time on creep of steels, tests on tin bronzes at elevated temperatures, continuous flow corrosion tests of pipe, hardness testing of light metals, relation between tension, static and dynamic tests, and a survey of testing in the precious alloy field. On cementitious and related materials there are papers involving concrete shrinkage, modulus of elasticity and Poisson's ratio of concrete, concrete disintegration, tests of mortars for reinforced brick masonry and pre-stressed ceramic members.

Other subjects covered in extensive papers include the effect of engine design and volatility on oil consumption, measuring soil resistance, stability of granular mixtures, wear test for flooring materials, physical properties of asphaltic mixtures at low temperatures, testing plastic caulking materials, distribution and variations of properties of southern yellow pine wood, and testing wool with the microscope.

* Parts I and II of the 1935 *Proceedings* can be purchased at $5.50 each in stiff paper cover ; $6, cloth ; and $7, half leather, from A.S.T.M. Headquarters, 260, S. Broad Street, Philadelphia.

Handling Steel Sheets in Pickling

NEW DESIGN OF CRATE TO FACILITATE QUICK LOADING AND UNLOADING.

To-day the question of pickling is recognised as one of the most important operations in the production of galvanised and black-steel sheets; this is due largely to improvements in equipment, which have resulted in increased efficiency. In this article an interesting type of crate is described which facilitates quick loading and unloading.

THERE is no doubt that the importance of proper pickling is now becoming more generally recognised, especially by the larger firms in the iron and steel industry and by the chief automobile producers. For some reason pickling has always been a rather neglected operation in the metal-working industries, and there are still many firms who practise "hand-scouring" and others who operate with no proper scientific control or adequate equipment.

Offensive fumes, irregular results, and generally discouraging conditions were almost universal a few years ago and they are not entirely eliminated. Gradually, however, these conditions are being dispersed in the light of modern thought and progress. This is being achieved as a result of operating executives concentrating on the subject and bringing about improvements in equipment, and consequently increase in efficiency.

A number of the crates showing the unusual design.

Loading one of the crates.

Pickling is the process of removing scale, oxide, rust, and other foreign substances from the surface of metals by immersing them in acid solutions, and the acid solutions, their strength, the temperature at which they are used, and the time during which the base material is subjected to the pickling process, are all important factors. The scale and rust which forms on steel sheets during production operations are normally removed by pickling in a solution of sulphuric or hydrochloric acids. Both are effective as pickling solutions, and both are necessarily destructive to pickling equipment.

Apart from mechanical damage, which is also likely to shorten the life of pickling equipment, the corrosion effect of the solution contaminates the bath and necessitates more frequent changing to maintain the requisite strength and cleanliness, particularly when large and heavy work is being processed. Thus, in view of corrosive damage and possible mechanical damage, it is generally wise to design and construct crates so that corrosion is limited as much as possible, and in such a way that the component parts can be readily repaired or replaced.

The pickling equipment employed at the plant of the Bowesfield Steel Co., Ltd., of Stockton-on-Tees, was designed with the foregoing considerations in mind. The output of this firm consists mainly of galvanised and black steel sheets, both of which require to be pickled after rolling. The work is carried out in 15 large Monel metal crates, specially designed to facilitate quick loading and unloading. As will be noted in the accompanying illustrations the design of these crates is unusual. They have hinged sides, and the work is held in position by removable round bars. This design enables operators to remove a few sheets at a time without disturbing the bulk of the work, but it was primarily adapted to facilitate loading and unloading.

The number of sheets held between the bars varies according to the gauge of the work. The size of the crates is 9 ft. by 4 ft., the bars being about 3 ft. high above the bottom frame; each unit is normally loaded with about 30 cwt. of sheets. The pickling solution employed contains approximately 3½% free hydrochloric acid, and is used at a temperature of about 80° F., and, contrary to the usual practice, the temperature is not closely controlled, but the results are quite satisfactory.

It is difficult to give an estimate of the service obtained from the crates because some parts are more susceptible to mechanical wear than others. Generally speaking, corrosion causes little trouble, although the upper portions which are out of the actual bath are attacked at a higher rate than the parts which are immersed; but so far Monel metal has proved to be the most satisfactory material to employ for pickling equipment. It possesses the necessary strength and toughness to resist mechanical handling, is highly resistant to corrosion by sulphuric and hydrochloric acids in the strengths normally employed for pickling solutions, and because of these properties gives much longer service than other materials, with less contamination of the acid solutions.

The practice of using Monel metal for pickling equipment is adopted by many large users both in this country and abroad, its application for this purpose is therefore well known. The main features of interest in the crates installed by the Bowesfield Steel Co., Ltd., are due to their ingenious design which makes them particularly applicable to the rapid handling of steel plates in the pickling process.

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Progress in the Development and Application of Aluminium and its Alloys

ALUMINIUM is the only common commercial metal which has not been known or used for hundreds or thousands of years. Isolated just over a hundred years ago by Wohler, it remained a laboratory curiosity until after the middle of the nineteenth century. Long and patient work was carried out by Deville, who, without intent, duplicated the experiments of Wohler and produced aluminium about 1845. He continued his work for several years in an effort to segregate pure aluminium in a less costly way, but his results were discouraging. Eventually he succeeded in producing larger quantities by means of a new process for abstracting the metal from natural ores with sodium. The success achieved in these later experiments led Deville to announce before the French Academy, in 1855, that he hoped to place the aluminium industry on a firm basis ; but a few years later he confessed that the introduction of a new metal to the service of mankind is an operation of great difficulty. He apparently appreciated that many difficulties remained to be overcome, for he said aluminium may become a useful metal, but the place it will occupy in daily life will depend upon man's estimation of it and its commercial price. It was not until the development of the electrolytic process, about 1886, that definite progress was made in the production of aluminium on a commercial scale. This development was due to the discovery of a new process by Hall in America and Heroult in France. In this process heat is generated by the passage of an electric current through a charge of ore, metallic aluminium sinking to the bottom of the furnace, from which it is tapped and cast into moulds. The process, which effected a marked reduction in cost, was substantially the same as that in operation to-day.

During the comparatively short time since its production on a commercial scale concentrated scientific and technical advances facilitated production and reduced the cost, and aluminium rapidly moved through the semi-precious metal stage to a metal of common use as we know it to-day. In the earlier days the advantage of its weight-saving properties gained some recognition, but a clear conception of the full possibilities of aluminium was not at once apparent. It became popular in the form of kitchen utensils because of its light weight and pleasing appearance, but towards the end of the nineteenth century it began to be applied to reduce the dead load in structures concerned with transportation. Its progress coincided with that of the automobile industry, which contributed to aluminium's phenomenal rise in a field which to-day consumes by far the largest percentage of aluminium and its alloys. Early in the present century sheet aluminium had be developed to such an extent that it was used for motor-car bodies, but keen price competition caused it to give way in favour of steel, excepting in omnibuses and many types of commercial vehicles, in which sheet aluminium continues to be used because the weight-saving is a vital factor in reducing operating costs.

In the transportation field the full significance of weight reduction was quickly appreciated on the railways and electric tramways. The high relative cost of power to drive the rolling stock employed resulted in investigations on the application of aluminium and its alloys. With increasing weight of rolling stock and increasing speeds, not only was the cost of motive power greatly increased but the effect on general maintenance was considerable. The advantages of employing aluminium alloys were soon apparent and their application to reduce dead weight, consistent with safety and economy, had been demonstrated. To-day the construction of railway coaches for light, fast railways, embodies considerable quantities of aluminium in the form of panelling, seats, window frames, doors and engine gear-cases.

As lightness is the outstanding attribute of aluminium it was natural that it should be employed in the construction of the more recent of the transport developments, aircraft. In this field the use of aluminium is almost obligatory and the use of light metal is a first consideration. It can be said that the development of aluminium and its alloys prepared the way for the progress experienced in the various types of aircraft. The discovery of magnesium, about one-third lighter than aluminium, stimulated research and invention in aluminium alloys which disclosed other valuable qualities, particularly resistance to attack by acids. Thus, while the magnesium alloys have become a serious competitor of aluminium alloys for aircraft construction, research has shown that aluminium has distinct possibilities in the construction of equipment for the chemical industry.

In shipbuilding the use of aluminium continues to expand, but its use is frequently ruled out on account of cost. Considerable impetus was given to its application in this field as a result of the weight limitations in warship construction. Weight reductions were effected by a freer use of aluminium alloys for such parts as scuttles, dead lights, port lights, oil fuel transmission, electric motor casings, stanchions, etc. ; submarines for instance, use aluminium pistons, while to-day most warships use a considerable tonnage in various directions. The development of these alloys in shipbuilding and marine engineering is reviewed by Dr. J. W. Donaldson in this issue, a perusal of which will indicate the remarkable strides made in these fields in the use of aluminium.

Considerable quantities of aluminium are absorbed in the electrical industries, not only for transmission cables, but for much detail and structural work in power-stations. It is now used to a considerable extent in architecture, particularly for internal and exterior decorations, as a result of the great variety of finishes now possible either on castings or the wrought material.

It has only been possible to summarise the major fields in which aluminium and its alloys have made remarkable progress. Although the commercial career of this metal may be said to have started in 1886 with the discovery of the electrolytic process, in just about half a century it has achieved fifth place in the family of metals. Certainly no other metal has made such rapid progress ; expansion of its field of usefulness is an achievement for which much credit is due to patient research work carried out in Germany, France, America, Great Britain and Switzerland. With increasing competition research work is proceeding with greater intensity and in view of the progress already made it can be assumed that the future holds immense possibilities for the further application of aluminium and its alloys.

Pyrometry

THE first known measurement of temperature, said Mr. A. Mould, in a recent paper before the Staffordshire Iron and Steel Institute, was made in the year 2 B.C. by some Greek physicians, but the term "Pyrometry" applies only to instruments designed to measure temperature above the range of the ordinary mercury thermometer, which is useless for temperatures above 700° C. Even at this temperature special silica has to be substituted for glass, which commences to distort at about 550° C., and so gives inaccurate readings.

The first attempt made to measure high temperature was made about the later stages of the nineteenth century, when J. Wedgewood made an instrument based on the contraction of clay when baked at increasing temperatures. In the early nineteenth century Seebeck had discovered thermo-electrity, and it was this which led to the present-day temperature control. Several people attempted to use thermo-electricity but failed, and it was not until the latter end of the nineteenth century that it was revived. When Hadfield discovered that 15° difference in the temperature from which a sample of steel was quenched made a totally different hardness in the finished specimen, a big demand was instantly created for very accurate temperature measurement.

The modern thermo-couple works on the principle that when two dissimilar metals are joined an electro-motive force is given off if the junction is heated. This does not imply that any two metals will give this effect, as all metals are not suitable. The principal conditions to which a thermo-couple must conform are that the electro-motive force developed should increase as the temperature rises, the melting point of either wire should be well above the highest temperature to be measured, the thermo-electric value should not alter by prolonged use, and the metal should be obtainable in uniform homogenous wires so that a junction, wherever formed, will give rise to the same electro-motive force. It was found that platinum and platinum-rhodium wires fulfilled these conditions. The platinum-platinum-rhodium couple is usually a pure platinum wire matched against a wire of an alloy of 87% of platinum and 13% of rhodium. With two refractory sheaths as a protection this couple can be used continuously at 1,350° C. and intermittently at 1,450° C.

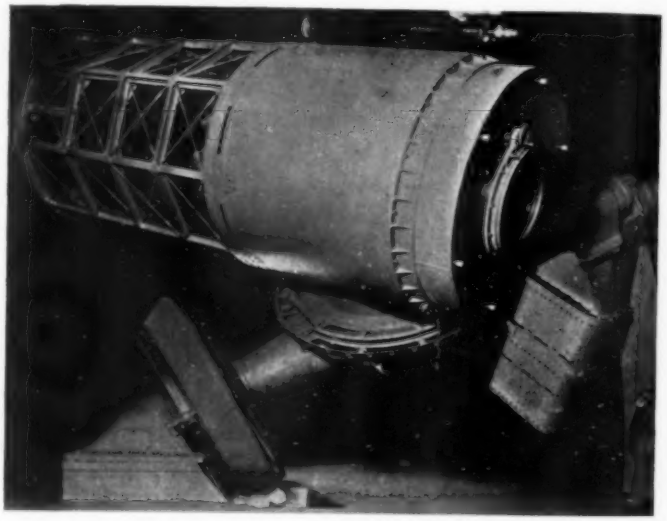
The cost of these wires however is high, so it has been necessary to find cheaper substitutes where possible; but above 1,000° C. the platinum-platinum-rhodium couple is the only one that can be used, as the substitutes will not act above that temperature. Two substitutes have been devised—one consisting of iron and constantan, the latter being an alloy of nickel and copper. This couple can be used continuously at a maximum temperature of 600° C. Another couple is the chromel-alumel couple. These wires are made of alloys of nickel-chrome and nickel-aluminium, and their range for continuous use is up to 950° C.

A new couple of non-metallic type, not yet in use to a great extent, is the silicon-carbide-carbon couple, and this is available for temperatures up to at least 1,800° C. It consists of a tube of compressed carbon with a rod of silicon-carbide down the centre. The two are joined at the hot-junction end, and insulated at the other end by means of a refractory ring. This prevents the rod from coming into contact with the carbon tube at any other point than at the hot junction; that is, the point where the heat to be measured is applied. The thermo-electric power of this couple is about thirty times as large as the platinum-platinum-rhodium type, and five times as great as the iron-constantan type. Small variations of temperature at the cold junction have very little effect on the calibration. Carbon-silicon-carbide is very stable, and the maximum temperature to which they may be subjected is about 2,700° C., the melting point of silicon-carbide.

Mr. Mould discussed other means of registering temperature by means of radiation. He referred to the radiating pyrometer perfected by Fery in 1904, and also to several types of optical pyrometers which have been devised, many of which are giving way to the disappearing filament type, which is now more frequently used.

The Second Largest Telescope

The second largest telescope in the world is to have important parts of nickel cast iron. The telescope is being erected on Mount Locke in South Western Texas, and will be housed under a rotating dome weighing 125 tons. The wheels which are to carry this weight are cast from special high-test nickel alloy iron to ensure maximum toughness, strength and machinability.



The telescope being erected on Mount Locke, claimed to be the second largest in the world.

The declination circle of the telescope presented a problem which led to the specifying of nickel cast iron for this part of the telescope's equipment. As this casting consists of a variety of sections, warping or cracking may well have occurred at the junction of heavy and light sections if ordinary cast iron had been employed. Because of its great uniformity of structure nickel cast iron reduces the possibility of cracking and provides a casting which is less susceptibility to distortion.

Light Alloy Handbooks

In the issue of September last attention was directed to the "Noral" handbook of light alloys, issued in loose-leaf form so that revisions and additions could easily be incorporated. Due to works extensions, and also to the increase in the number of alloys, revisions and additions to this handbook have now become necessary, and new sheets for this purpose are available. The additions covered by these new sheets include particulars of a new alloy—NA 57S. This is an aluminium-magnesium-chromium alloy of the non-heat-treated type, which has high strength and excellent resistance to atmospheric and seawater corrosion. Various additions have been made to the list of alloys available to B.S.I. and D.T.D. specifications. Particulars are given of 250 new extrusion dies; the range of sections which can be extruded has been extended to cover sections in all alloys up to a maximum overall width of 8 in. Loose leaves, giving these revisions and additions, are available from Northern Aluminium Co., Ltd., Bush House, Aldwych, London, W.C. 2.

Aluminium Alloys in Shipbuilding and Marine Engineering

By J. W. DONALDSON, D.Sc.

This is an age of metals and production is steadily rising. Particularly is this true of aluminium, the production of which is increasing at a much more rapid rate than that of other metals. During recent years extensive work has broadened the structural use of aluminium in the land transportation field ; to-day it is gradually being applied in shipbuilding and marine engineering, and this article reviews the progress in these fields.

By courtesy of Birmabright, Ltd.

Sixty-five feet Patrol Cruiser "Interceptor," built entirely of Birmabright alloy.

THE development of the light alloys of aluminium and their extended use in the automobile and aircraft industries has had a certain influence on other branches of industry. The post-war naval programmes, as a result of the limitation of tonnages, initiated a campaign not only for lighter machinery, but also for lighter materials of construction for certain parts in shipbuilding, and the results obtained from the use of such alloys have led during recent years to their introduction into the construction of naval vessels and of passenger ships, and there is every indication that their application will be greatly extended in the near future. That aluminium and its alloys were not more extensively used for marine work at an earlier date resulted from the lack of satisfactory corrosion resistance in such alloys, and also to lack of knowledge of their treatment and manipulation. To-day, many high-tensile alloys of sufficient corrosion resistance are available, methods of protection have been adopted to mitigate corrosion, and other deficiencies have been taken care of by giving more thought to design.

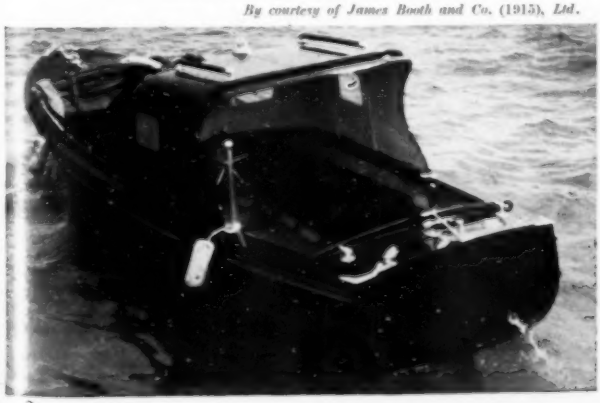
Alloys Used

Alloys of aluminium suitable for casting purposes for marine work and possessing good physical properties in their cast condition, or after suitable heat-treatment, are to be found in such materials as the aluminium-silicon alloys—the Y alloy, the RR alloys 50 and 53, and Ceralumin. According to their condition and treatment such alloys possess tensile strengths ranging from 10 to 25 tons per sq. in., are tough, and have satisfactory foundry properties for giving good castings. The outstanding wrought alloys, which have been found suitable for similar work, include Duralumin, in its various forms, the aluminium-magnesium alloy known as Birmabright, the RR alloys 59 and 66, and the high-strength alloy known as MG 7. These alloys have tensile strengths ranging from 18 to 30 tons per sq. in., and also fairly good ductilities. The specific gravity of these various alloys, cast and wrought, range from 2·75 to 2·95, with the exception of the aluminium-silicon alloys, which have specific gravities ranging from 2·6 to 2·7, while the modulus of elasticity of all these alloys is more or less constant at 10,000,000 lb. per sq. in., whatever the tensile strength. When the physical properties of these aluminium alloys, and particularly of the heat-treated alloys, are considered in relation to their specific gravity, it is at once clear that light alloys can be used in place of most ferrous and non-ferrous alloys, thereby effecting a substantial saving in weight.

Under ordinary conditions of service modern aluminium alloys are capable of resisting corrosion conditions, provided they are protected, as cast iron and steel parts are protected, by paint or other suitable coating. It must be remembered, however, that in the painting of light alloys care must be taken that suitable paints are used, and that the metal surface is suitably prepared before the paints are applied. Alloys which have been subjected to solution heat-treatment, followed by natural ageing, are the most resistant to corrosion, and can be used under most conditions without protection. What applies under ordinary service conditions applies also in marine work, except where parts are constantly wet or subjected to salt spray or a sea atmosphere, when the best protection is afforded by anodic treatment.

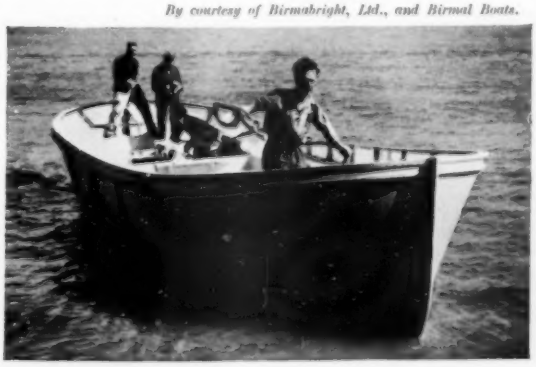
A launch used by the Royal Yacht "Britannia." It is constructed almost entirely of M.G. 7 metal.

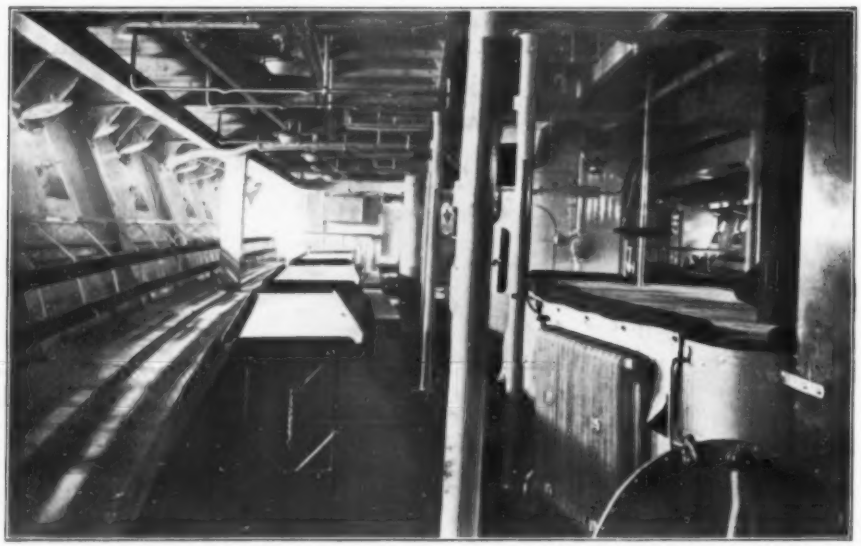
By courtesy of James Booth and Co. (1915), Ltd.



Thirty feet Ship's Lifeboat, seating 99 persons and built entirely in Birmabright alloy.

By courtesy of Birmabright, Ltd., and Birmal Boats.





By courtesy of British Aluminium Co., Ltd.

Upper mess-deck of a torpedo-boat destroyer, showing the use of aluminium for seamen's lockers, ventilator trunking, ditty-box racks, boot racks, cap-box racks, etc.

Electrolytic interaction between aluminium alloys and other metals used in combination with it must also be guarded against, particularly where moisture and sea-water are present. Utilising the various alloys mentioned, protecting them by suitable methods, and fabricating them under suitable conditions have done much to dispel early prejudices, and have given materials which have allowed of a considerable saving of weight in certain branches of the shipbuilding and marine engineering industries.

Hull Construction

Aluminium alloys have not yet been used in the hull construction, or in the superstructures of ships, to any extent except in the case of very small craft, despite the fact that it has been suggested that a large reduction in weight would be attained if light alloys were used for the main structural work of a vessel. It has been shown that in the case of cargo ships not only is the cost of such alloys considerable, but also that cargo space is more important than deadweight, and that, if a definite deadweight is required, the use of lighter alloys in place of steel would lead to a smaller ship and smaller cargo space unless the design of the modern cargo ship was radically altered. In large passenger ships this question does not arise to the same extent, as passenger accommodation can always be increased by building upwards, and the use of lighter materials in upper structures would either improve stability by decreasing weight, or allow of increased superstructures with more accommodation space without loss of stability. Another point which has got to be considered is the saving in weight obtained in relation to the cost of the alloys used. Mild steel has a specific gravity of 7·5, as against 2·8 for aluminium alloys; but it does not follow that in substituting such alloys for steel a corresponding reduction in weight would be attained. In a ship's structure the larger number of parts are alternately under tension and compression, and due to the low modulus of elasticity of light alloys in comparison with steel it would be necessary to increase the sections of beams and frames or to increase the number of those members in order to obtain the same rigidity and stiffness. These facts, together with the difficulties experienced in the fabrication of light alloys, are the principal reasons why such materials have not yet been used to any marked extent in the superstructural parts of large vessels.

The largest vessels constructed so far of light alloys, where such alloys have been used for the hull and superstructure, are the 55-ft. motor-cruiser, *Diana II*, and a 65·6-ft. motor-cruiser for the Royal Canadian Mounted Police. The light alloy used in the construction of these vessels was the aluminium-magnesium alloy known as Birmabright. The plating, sections, and rivets for the frame structure of the hulls and bulkheads were rolled and extruded from this alloy. Deck fittings, pillars, stanchions, brackets, and many fittings for the saloons and cabins were Birmabright castings, while such parts as fuel tanks, compartments, ladders, and the masts were constructed of rolled sheets. A passenger motor-vessel, which carries 200 passengers, has also been built for service on Lake Lucerne.

The Yacht "Wutamoe" with its aluminium-alloy mast.

By courtesy of Aluminium Union, Ltd.

Complete aluminium state-room.

By courtesy of Aluminium Union, Ltd., and "Revue d'Aluminium."

The hull of this vessel is of arc-welded steel, protected by a sprayed zinc coating, and the deckplates and superstructure, including deck-houses, seats, window frames, and skylights, are of an aluminium alloy known as Anticorodal. The deckplates, which are 5 mm. thick, are riveted with aluminium rivets to the steel supports, and corrosive action is prevented by painting with white zinc paint, or coating with sprayed zinc, and the various parts of the superstructure are also riveted, except in the case of the skylights, which are welded.

Ship Equipment and Fittings

Apart from the hull the general outfit of a ship includes many parts in which aluminium alloys can be used with advantage to replace parts in steel, cast iron, and more especially in brass and bronze, thereby showing a considerable saving in weight, and at the same time justifying themselves from an economical point of view. Such parts include ships' equipment, cabin fittings and furniture, electrical parts, and many parts connected with marine engines, particularly of the Diesel type. Pure aluminium is also being used for insulating purposes and in the form of paint.

Ships in which light alloys are being increasingly used for equipment are warships and large passenger ships. Aluminium-alloy castings, usually Alpax, are particularly suitable for deadlights and sidelights, and for window and skylight frames, although the latter are also made in extruded sections from some of the wrought alloys. Such parts are light and are easily operated, and if subjected to anodic treatment or painted, resist corrosion well. Pure aluminium, Duralumin, or some other wrought alloy, in the form of sheets or sections, are suitable for the fabrication of ventilating trunks and fans, and the same materials are also used in the construction of lifts in passenger ships for gates and cages. For the latter purpose aluminium alloys are not only light and durable, but bright matt or oxidised surface finishes are obtained, which fit in with decorative schemes.

Control gear, telegraphs and binnacles, search-light bodies and pedestals, small fittings and brackets, stanchions, hand-wheels, and instrument cases are made from aluminium-silicon alloy castings or from aluminium-alloy pressings. Pure aluminium is largely used in all classes of ships for voice pipes on account of its lightness, and in the form of tubes it is suitable for electrical conduits, being easily installed and fitted. Switches, switch plates, switch covers, and lighting fittings are also made from pure aluminium, and when treated by the anodic process have a decorative and permanent finish. Castings of Alpax are found to be suitable for such electrical parts as low-power junction boxes, fuse boxes and switch boxes.

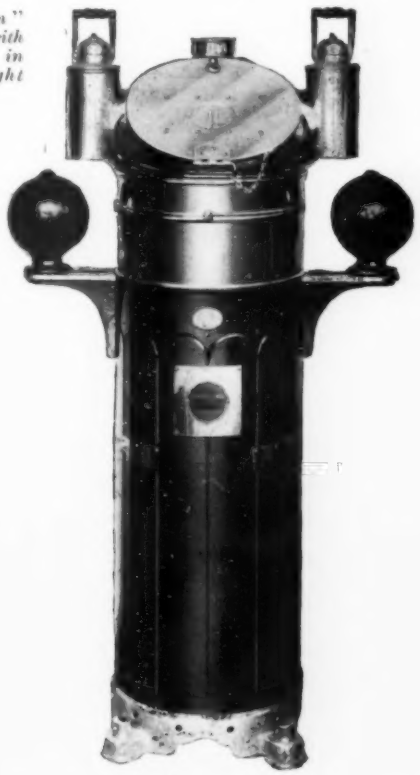
By courtesy of Aluminium Union, Ltd.

Fireproof aluminium state-room and furniture.

In the equipment of cabins, Duralumin, Birmabright, and similar alloys are now commonly used for furniture, lockers, and fittings hitherto made of wood. Aluminium furniture is not only installed on board ship in order to save weight, but also to minimise the risk of fire. The *Maribosa*, the first merchant ship to have aluminium furniture in quantity, had 570 chairs of 11 lb. weight each installed

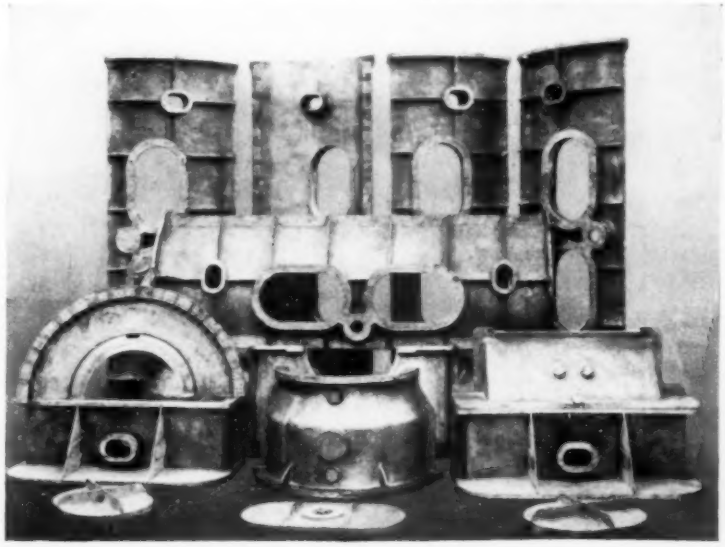
By courtesy of Birmabright, Ltd.

A "Husun" binnacle with metalwork in Birmabright alloy.



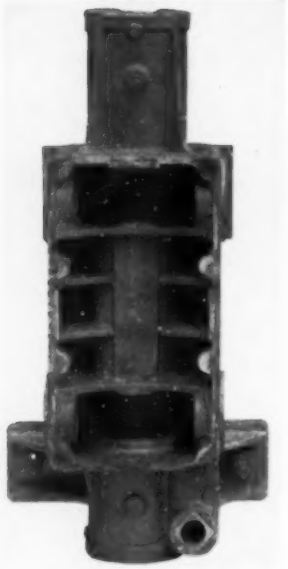
Group of castings of turbine gear-casings in aluminium alloy.

By courtesy of Northern Aluminium Co., Ltd.



By courtesy of British Aluminium Co., Ltd.

Group of Diesel engine parts for marine work, all in aluminium alloy, manufactured by Vickers, Ltd.



By courtesy of High Duty Alloys, Ltd.

Valve-gear casing in Hiduminium R.R. 50.

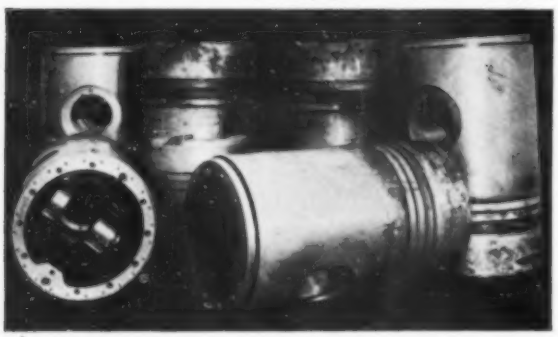
in the dining-room, the chairs being fabricated from strong wrought aluminium alloys. Series of tests have been carried out on the inflammability of materials used for furniture, cabin bulkheads, ceilings, panelling, and other fittings, and the results obtained have shown that aluminium alloys have a fair resistance to the severe testing conditions applied. In the United States aluminium and its alloys are classified as a "Class B" fire-resisting material, capable of withstanding a temperature of 1,000° F. (538° C.) for 30 minutes. The use of light alloys for panelling, light bulkheads, mouldings, and skirtings, is now established, and although now only used to a limited extent will no doubt show a considerable increase in the near future. Another use of aluminium alloys in their polished or anodised state is for such parts as taps, rails, hooks, and bathroom and cabin fittings in general.

The use of crumpled aluminium foil, instead of granulated or slab cork, covered by a protective sheet of aluminium or galvanised iron has been largely adopted during recent years for insulating purposes in refrigerating spaces and for decks, and is now standard practice for warships and fast passenger ships. The thin sheet of crumpled aluminium presents a series of small points of contact, so that the conducting power is very small, while the polished foil reflects the heat and so prevents radiation. The advantage obtained in the use of aluminium foil as an insulating material is in the large reduction of weight effected, as the thin foil weighs only about a seventieth of the weight of cork, which would be required to give equal insulation.

The use of aluminium paints on board ship is rapidly increasing, and such paints are now largely used on all naval vessels and passenger liners. Aluminium paints, besides being light in comparison with other paints, are extremely resistant to corrosion and have a high opacity and reflecting power, which renders them resistant to the destructive action of ultra-violet light. These properties, and particularly their weight, when compared with lead paints, render them particularly suitable for ship work, and as regards appearance, internal lighting, and ease of application, they compare favourably with other types of paint. While dealing with paint, reference might also be made to the fact that the appearance and surface finish of aluminium alloys, when they are used for cabin furnishings, fittings and other parts, renders their painting unnecessary, and thereby reduces weight to a certain extent, as it is always necessary to apply two or three coats of paint to such parts if they are made of wood or steel, and the weight of such paints has always to be reckoned with.

Group of Diesel engine pistons for marine work in (Lo-Ex) aluminium alloy.

By courtesy of Northern Aluminium Co., Ltd.

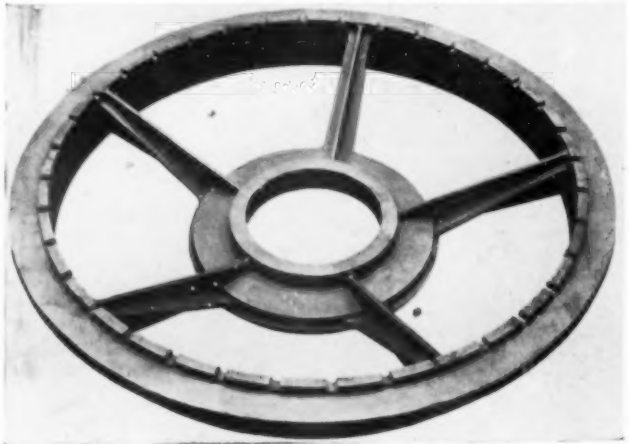


Aluminium Alloys in Marine Engineering

In marine engineering cast aluminium-silicon alloys, on account of their lightness, strength and corrosion-resisting properties, have been used for a variety of purposes both in turbine and in Diesel engine work. Parts such as gear-cases, crankcases, cylinder-head covers, inspection doors, pipe-line junctions, are now made regularly from these alloys, as are also valves and filters in fuel and lubricating oil systems, and pumps handling water and oil at pressures up to 350 lb. per sq. in.

A control-gear casting in Hiduminium R.R. 50.

By courtesy of High Duty Alloys, Ltd.



By courtesy of High Duty Alloys, Ltd.

Large Diesel engine piston in Hiduminium alloy.

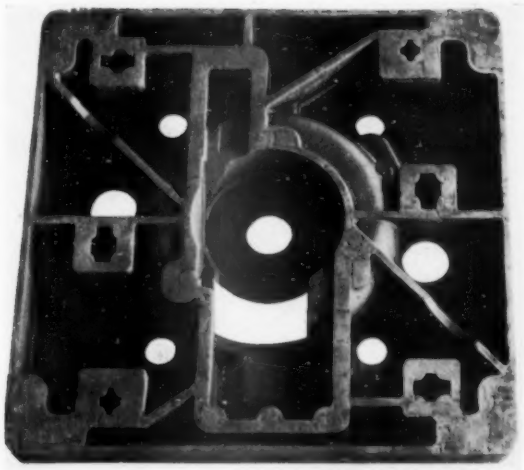
Aluminium alloys have also played an important part in the development of the high-speed internal-combustion engine for marine purposes, not only on account of their lightness, but also on account of their low thermal conductivity. Reduction of inertia forces, resulting from the reduction of reciprocating weight, which is an important factor when dealing with high-speed engine inertia forces and bearing pressures, have allowed of the use of larger diameter pistons being used before piston cooling is necessary. Pistons for these types of engines were originally made from aluminium alloys containing 8 to 10% of copper and other alloying elements, but such alloys have been replaced during recent years by the heat-treated, age-hardened Y alloy, and casting alloys of the R.R. type.

The aluminising of iron and steel by spraying aluminium over iron or steel, so that when the iron is heated the aluminium and the iron diffuse to form a thin alloy coating, has also proved of extreme use in marine engineering. Material so treated withstands temperatures up to 900° to 1,000° C. without scaling, and has been used for parts such as boiler superheaters, exposed on both sides to hot gases, superheater fasteners, and baffles. Originally used on the German liners *Bremen* and *Europa*, where over 80,000 sq. ft. of boiler material was so treated, the process has been widely applied both in naval and mercantile work. Boiler tubes in large marine boilers have also been treated by this method against the action of boiler gases, and such tubes have been found to be satisfactory after many years' service.

In fabricating aluminium alloys for marine engineering purposes, care has always to be taken to prevent electrolytic action between the alloys and the other metals used in combination with them. Screw threads in light alloys must also be avoided, if parts are to be disassembled, and where such screws are necessary the parts required to be bushed. Both oxy-acetylene and electric-arc welding are used in the fabrication and necessitate a high degree of skill and careful inspection if reliable joints are to be attained.

Uses in Small Craft

In small motor-boat construction, for dingys and canoes, and in parts of yachts, aluminium alloys are coming more and more to the front. Aluminium masts have been popular in racing yachts since 1930, when the *Enterprise* was fitted with a mast made from Duralumin, and the use of light alloy for deck fittings and other parts does much to reduce weight and to facilitate the speed of such craft.



By courtesy of High Duty Alloys, Ltd.

A control-gear casting in Hiduminium R.R. 50.

New Steel-rolling Plant at Zaporozhe

A new steel-rolling plant, said to be the largest in Europe, is being built by the Zaporozhe Steel Trust at Zaporozhe in the Ukraine. The plant is intended to supply the bulk of the steel required by the automobile industry of the Soviet Union. It will contain three huge rolling mills—one for the rolling of sheet steel, with an output capacity of 1,200,000 tons a year, another for the production of thin sheets, with an output capacity of 600,000 tons a year, and the third for the production of sheets of an average thickness, with an output capacity of 340,000 tons a year.

The Iron and Steel Institute

The annual meeting of the above Institute will be held at the Institution of Civil Engineers, Great George Street, Westminster, S.W. 1, on May 7 and 8. In addition to the business meeting and the presentation of awards several papers will be presented for discussion. These will include "Some Considerations Influencing Plant Facilities for Strip Sheet Production under British Conditions," by Mr. G. A. V. Russell; "A Study of the Influence of Varying Degrees of Cold-Rolling and Annealing Temperatures on the Properties of Mild Steel Sheets," by Dr. C. A. Edwards and others; "A Survey of the Iron-Carbon Diagram near Zero Carbon (below 1,000° C.)," by Mr. J. H. Whiteley; "The Embrittlement of High-Tensile Alloy Steels at Elevated Temperatures," by Mr. W. E. Goodrich; "The Behaviour of Five Cast Irons in Relation to Creep and Growth at Elevated Temperatures," by Messrs. H. J. Tapsell, M. L. Becker, and C. G. Conway; "Internal Stresses and their Effect on the Fatigue Resistance of Spring Steels," by Messrs. M. L. Becker and C. E. Phillips; "Further Experiments on the Effect of Surface Conditions on the Fatigue Resistance of Spring Steels," by Messrs. G. A. Hankins, M. L. Becker and H. R. Mills; "The Influence of Light on the Electrode Potential and Corrosion Phenomena of Mild Steel," by Messrs. C. O. Bannister and R. Rigby; "Factors Influencing the Rate of Attack of Mild Steels by Typical Weak Acid Media," by Messrs. T. P. Hoar and D. Havenhand; "Methods of Detinning Tinplate for Examination of the Thickness and Continuity of the Alloy Layer," by Messrs. A. W. Hothersall and W. N. Bradshaw; and "A Study of the Origin of Porosity in the Tin Coating of Tinplate," by Messrs. A. W. Hothersall and J. C. Prytherch.

Recent Advances in Metallurgy

Several important discoveries which are facilitating the development of metallurgy were discussed by Professor D. Hanson in a recent lecture, certain aspects of which are summarised in this article.

IMPROVED methods of investigation have greatly facilitated development in metallurgy. This was emphasised by Prof. D. Hanson in a recent lecture delivered before the Midland Metallurgical Societies, in which he confined himself to a few aspects of physical metallurgy. Some of the investigations to which he referred were a little difficult and rather involved, but he presented them in a simplified form.

The developments and extension of heat-treated non-ferrous alloys which may be made amenable to age-hardening, could only be explained and perfected by investigations into their construction. Ternary alloys, such as the nickel-silicon-copper, and nickel-tin-copper alloys were becoming increasingly important. The microscope had obvious limitations—it could not tell them what the substances in their alloys actually were, while the chemical analysis of these alloys told them even less, and until quite recently all they could tell from the microscope was whether they were dealing with solid solutions or what were termed compounds, without a knowledge of either.

The developments which had given knowledge of the different phases were most spectacular. It was a subject which was developing at the present time, and formed part of the general study of the nature of the solid state of matter about which we knew actually very little indeed. We saw things through the microscope by the use of light of a certain wave length, and anything which was of the wave length of light or of smaller wave length, the microscope took no notice of, and in order to find out about those things which were smaller than the wave length of light, something else had to be used. X-rays, introduced by Lane, was used for this purpose. He realised that the atoms of a metal crystal were arranged regularly in space, and the distance between the atoms was about the length of the waves of X-rays. By taking X-rays and allowing them to fall on metals and observing the manner in which those rays were scattered it was possible to see where the atoms were inside the metal. That told a lot about metals that was not known before. It was found that the atoms were arranged according to space lattices—that the arrangements of these lattices differed from metal to metal, but that there were a strictly limited number of the lattice types. Most of the ductile metals belonged to one class, metals like zinc and magnesium to another, iron, tungsten and molybdenum to another, while tin, bismuth, and antimony belonged to yet other types of structure, and these four or five types of structure covered the whole of all types of metals.

It was therefore possible, continued Professor Hanson, to define the metals by their atomic structure, but we know that alloys consist of solid solutions, so the next problem which called for solution was—what were solid solutions? If one took a certain lattice and inserted other atoms into it, such as with aluminium and copper, how would one expect the aluminium atoms to arrange themselves within the copper atoms? He did not think anyone could have told that without investigation. X-rays had told them the answer to most of the questions involved. Let us consider what happened to the lattice pattern when one element dissolved in another. Copper had a unit cube of 3.61 Angstrom units. The addition of aluminium expanded the lattice and made it bigger. The atoms actually moved further away from one another. Again, in the system of gold-copper alloys, the gold crystal was contracted when copper was added to it, and the copper crystal expanded. In doing that where did the stranger atoms go to? Copper atoms might take the places which ought to be occupied by gold atoms, or copper atoms might find positions in between the gold atoms. X-ray analysis would tell us that. If we measure the size of the unit cells, and at the same time measure the density of the alloys, then knowing the number of atoms and knowing the spacing, we can calculate what the resulting density ought to be. In most metallic alloys the atoms go into solution by substitution for parent atoms. In any systems of alloys we have to deal with a variety of solutions—for instance, when zinc is added to copper solid solutions are obtained which form the different classes of brasses. What are all these different phases? We used to think they were all compounds, and we tried to find formulas for them, but with little success. To a large extent we have now discovered what they were. Copper is, of course, a face-centred cube of 3·608 Angstrom units. As zinc is added to the structure, this is expanded and altered as the zinc is increased. The beta phase is centre cubic with a parameter of 2·946 Angstrom units, while the gamma phase is a more complex cubic structure containing 52 atoms in the unit cube. We have therefore discovered that the different phases are, in effect, different types of structure. The amazing thing is that although there are all these different phases in metals, the number of lattice types are very small. In that, they differed from ordinary chemical compounds in which the type of crystal is, in effect, a reflection of the molecule. The valencies of the different atoms determined the way in which they hang together, and there are a number of types of crystals in which similar atoms always occupied similar positions. In alloys, they differ from ordinary compounds in that the valency bond is much less. Compounds are frequently non-stable and frequently dissociated before they melt.

Professor Hanson continued by saying that the next advance was due to discoveries between the different phases. It was noticed that the beta phase had very similar properties in many instances. They had less ductility than the alpha phase, whereas the gamma phase was brittle. It was noticed that the higher the valency the lower the change. A very interesting generalisation was that the intermediate phases conformed to a few types, and the difference in type of phase was due to the ration of free electrons to atoms. Broadly, the rule was that for each lattice type there was a ratio of free electrons to atoms. There were so many that conformed to this rule that there was every reason to believe that it had a sound foundation in fact.

The gamma structure is a cubic structure with 52 atoms in the unit cube. The pattern of the atoms is the same for copper-zinc, silver-zinc, gold-zinc, and the copper-cadmium alloys, but if we examine them very closely we find the distribution of atoms in the pattern varies from system to system. In isomorphous compounds similar atoms occupied similar positions, but in alloys of the character mentioned, similar atoms did not occupy similar positions. This is the next important discovery with regard to phases, not only is there a limited number of lattice types, but it is beginning to appear that the nature of the types is independent of the nature of the atoms.

The technique of all this is not too difficult for the younger man to understand and to grasp, but the fuller understanding of the nature of crystals will probably involve investigations into the distributions of the electrons, and work was proceeding in that direction.

Ferrite Banding in Forged and Rolled Steel

By A. V. PROHOROFF
(Central Institute of Metals, Leningrad, U.S.S.R.)

In this paper the author gives a brief account of practical facts known about the banded structure of hot-worked steel, then reviews existing theories on the origin of ferrite banding, and shows by very simple experiments that this defect may be caused by non-uniform distribution of Si, Mn, Ni, and other elements capable of persistent dendritic segregation. Accompanying micrographs illustrate the mechanism of ferrite bands formation. It is shown that ferrite banding is due to carbon rediffusion on slow cooling through critical range to areas rich or poor in segregates, depending on the effect of the segregating elements on the critical points of steel. A suggestion is made that ferrite banding may be prevented and the directional effect of primary banding on the physical properties reduced by balancing the composition of a steel so that the alloying elements which segregate in interdendritic spaces would oppose each other in their influence on the direction of carbon rediffusion.

THE fibrous structure of forged and rolled steel is quite familiar to those who examine fractures or deep etched sections of hot worked bars at different angles to the direction of working (Fig. 1).

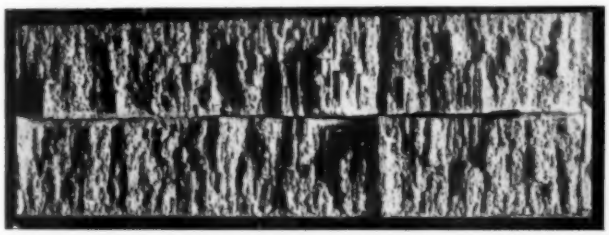


Fig. 1.—Fibre in longitudinal fracture of a disc, cut from a rolled and annealed bar of a Mn-V-Mo steel. Actual size.

Non-uniform distribution of alloying elements and impurities in primary crystals (dendrites) of steel in an ingot is responsible for the "fibre" in hot-worked steel. The larger dendrites and the more prominent segregation lead to more pronounced fibre. The more the ingot is worked the finer is the fibre and the more pronounced is its directional effect on the physical properties of the steel. While properly conducted hot-working operations considerably improve the properties of the cast metal, too much work often causes reduced ratio between the physical properties of transverse and longitudinal test bars. Especially affected are the figures for impact value, elongation and reduction of area. Frequently the impact values of transverse test bars is only 40–50%, elongation and reduction of area 50–60%, and tensile strength 90–95% of the corresponding figures shown by longitudinal test bars. If a considerable amount of non-metallic inclusions are present in a heavily-reduced bar, the plastic properties of the transverse test bars may fall extremely low; although the properties of longitudinal test bars from the same material may be excellent and the tensile strength of transverse test bars satisfactory.

Apparently the best practice in the production of high-strength forgings is to use reductions from original ingot of approximately 3 : 1, taking care that the forging methods used insure proper fibre flow, in accordance with direction of stresses to which the forging will be subjected in service. Greater reductions usually do not bring any appreciable improvement of the properties in the longitudinal direction, but noticeably lower them in the transverse direction. Some steels are more sensitive than others to variations in the degree of reduction.

When a polished surface of a fibrous fracture is subjected to the action of a cupric reagent, so called "Primary Banding," is shown by the selective deposition of copper on areas low in segregates (Fig. 2). It can be examined by the naked eye or with aid of a microscope—depending on the character of the structure and etching technique used. Primary banding closely corresponds to the fibre seen in a fracture, and is due to the persistent dendritic segregation of slow diffusing elements, which can be found in every steel, and is little affected by the carbon content and ordinary heat-treating operations.

Going further in these experiments and etching the repolished surface of the same sample with the usual acid solution reveals secondary or ferrite banding (also called "ghosts" or "ghost lines," when bands are very wide). This structure is characterised by non-uniform distribution of carbides and is built up of alternating ferrite and pearlite bands (Fig. 3). In some cases ferrite bands coincide with the purer primary bands (on which copper is deposited when etching with a copper reagent), in other cases they coincide with primary bands rich in segregates. Ferrite banding may be revealed in steels containing about 0·1 to 0·5% carbon, slow cooled from temperatures not

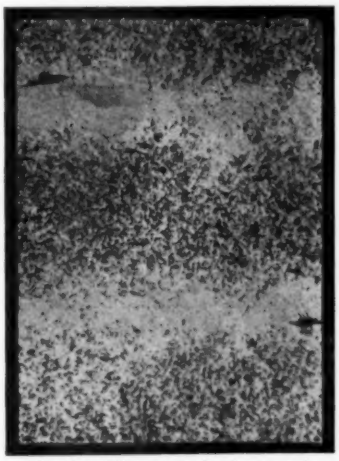


Fig. 2.—The same fracture as in Fig. 1, after quenching, polishing and etching with Le Chatelier reagent. Primary banding is brought to sight by selective deposition of copper on areas poor in segregates. Sulphide inclusions are located in bands that are rich in segregates, and which being unaffected by this etching remain bright. Magnification × 200.

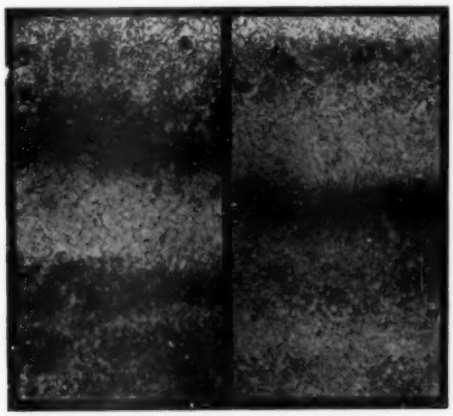


Fig. 3.—The same fracture as in Fig. 1 (in annealed state) after polishing and etching with 2% Nital. Ferrite banding. In this steel sulphide inclusions are located in pearlite bands exclusively. Magnification × 200.

very much above the upper critical point. Fast cooling through the critical range usually prevents the development of ferrite bands, which indicates that there is some force tending to cause carbon migration to certain bands on slow cooling. If a piece of steel with ferrite banding is heated so that considerable austenite grain growth occurs, ferrite banding does not appear again even if it is cooled very slowly. Many attempts were made to eliminate ferrite banding completely by heating samples of steel to very high temperatures for long periods of time, but few were successful.

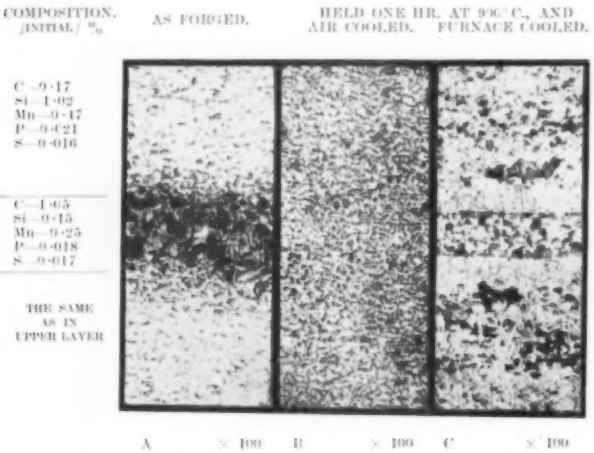


Fig. 4.—Effect of silicon on carbon rediffusion: on slow-cooling carbon migrates to areas low in silicon.

In most cases a grain refining anneal was sufficient to bring ferrite banding back after it seemed to be removed by a homogenising treatment. Johnson and Buechling[1] report that four hours' treatment of 4-in. rounds of a Cr-Mo steel (SAE 4,130) at 2,050° F. was sufficient to completely remove ferrite banding though, it reappeared in tubing pierced from these bars.

Alloy steels often show, on moderately fast cooling, a peculiar type of banding which is built up of pearlite-sorbite, sorbite-troostite or troostite-martensite bands. This type of structure is also closely related to primary banding, and is due to different critical ranges and critical rates of transformation of metal in adjacent bands which vary in their content of alloying elements.

Materials very rich in non-metallic inclusions and slag display in longitudinal sections a structure that may be termed slag banding (as in wrought iron, for example), and can be observed both on etched and unetched surfaces of a polished sample. In most cases slag banding is accompanied by ferrite banding: streaks of slag and inclusions being located in the ferrite bands (but in some types of steel inclusions may be located exclusively in pearlite bands, as shown in Fig. 3).

This circumstance gave rise to the first explanation of ferrite banding phenomenon, which was proposed by Brearly[2] in 1909. He suggested that elongated inclusions act as nuclei on which ferrite is precipitated from austenite as steel cools down through its critical range,—much in the same way as a cotton thread suspended in a sugar solution causes precipitation of sugar crystals on its surface.

Later, in 1914 Stead[3] demonstrated by some very interesting experiments that phosphorus can cause ferrite banding in steel by forcing carbon out of interdendritic spaces to purer dendritic axes. In 1918 Le Chatelier and Bogitch[4] suggested that segregation of oxygen rather than phosphorus leads to ferrite banding in steel.

Most of the numerous and very interesting investigations on the subject that followed later were concerned with these three theories; efforts were made to supply experimental data supporting one of them. No common agreement as to the origin of the phenomenon could be reached, and very little attention to other possible factors was paid, in spite of the fact that some of the alloy steels are the most susceptible to ferrite banding, and that segregated alloying elements are extremely slow to diffuse in solid steel even at very high temperatures.

For these reasons, the author decided to investigate the possible influence of non-uniform distribution of some of the alloying elements on carbon migration during slow cooling of steel through its critical range. A series of very simple experiments were conducted on different kinds of silicon, manganese and nickel steels welded together with carbon steels to create artificial segregation of the elements. Representative analysis of some of the steels used in these experiments are shown on the accompanying illustrations (Fig. 4 to Fig. 7).

Samples were prepared by forge-welding piles being built of different steel strips with well-cleaned surfaces and placed in a 1-in. steel tube together with a small amount of carburizing compound to avoid oxidation. Total time of heating a tube and forging it flat to a thickness of $\frac{1}{4}$ in. was about 10 to 15 mins., which was, however, sufficient for some carbon diffusion to occur (see Fig. 4, A). Excellent welds were thus obtained, but the thickness of the central strip of plain carbon steel varied somewhat in different portions of the same sample. Small specimens cut from three forged metallic strips were put in a small electric furnace, held 1 hr. at a temperature above the upper critical point and cooled at different rates. Each experiment was repeated several times and on several kinds of steels of the same type. Small variations in the content of impurities did not influence the results.

In properly quenched specimens no banding could be revealed by Nital etch, the whole of the surface of the specimen having a uniform martensitic structure when examined under a microscope. Only a slight difference in colour of martensite in the central strip of plain carbon steel, and in the surrounding alloy steel could be detected.

Air-cooled specimens also show a rather uniform distribution of carbon due to diffusion which took place at temperatures above Ac_3 (see Fig. 4, B). Banding displayed by some of these specimens (see Fig. 5, A and Fig. 6, A) is due to the influence of alloying elements on the structure of steel. Manganese steel, for instance, has a sorbitic structure, whereas the central band of plain carbon steel has a ferrite-pearlite structure.

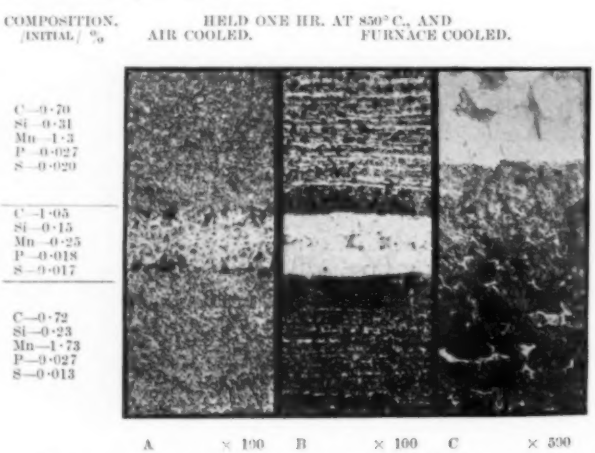


Fig. 5.—Effect of manganese on carbon rediffusion: on slow-cooling carbon migrates to areas rich in manganese. Note the eutectoid rim on both sides of wide ferrite band in the centre.

Extremely interesting phenomenon occurred in specimens left in the furnace to cool slowly at a rate of about —4° C. per min. (see Figs. 4, C, 5, B and 6, B). Considerable carbon migration took place which led to formation of very pronounced ferrite bands both in area of welds and in the body of surrounding metal. This kind of carbon migration, leading to non-uniform distribution of this element on slow

1 *Tr. A.S.M.*, 1924, vol. XXII, No. 3, p. 249.
2 Proceedings of the Sheffield Soc. of Eng. and Met., 1909, vol. 2, p. 56.
3 *Journal of the Society of Chemical Industry*, 1914, vol. 33, p. 173. See also *Journal of the Iron and Steel Institute*, 1918, I., p. 287.
4 *Comptes Rendus*, 1918, vol. 167, p. 472. See also *Revue de Metallurgie*, "Memoires," 1919, vol. 16, p. 129.

cooling from Ar_3, may be termed "re-diffusion," to distinguish it from "diffusion," which tends to create uniform carbon concentration and, starting at Ac_1, takes place between A_3 and A_4. Evidently, carbon rediffusion may occur under certain conditions only after diffusion.

Figs. 4, C, 5, B and 6, B show that ferrite bands formed are rich in silicon and low in manganese and nickel. The first of the elements raises the critical points of steel, whereas the second two lower them considerably. On the other hand, silicon and nickel promote graphitization, whereas manganese forms carbides. This indicates that the carbide-forming tendency of segregated elements does not determine the direction of carbon re-diffusion, and that the latter is governed by local differences in critical ranges.[5]

But, in the presence of sufficient quantities of elements that form very stable carbides, the process of carbon rediffusion may be partly or wholly prevented through the carbon combining with that element and building carbides which go out of solid solution at high temperatures, and do not take any part in the processes which occur on subsequent slow cooling. This is illustrated by Fig. 7, where the results of experiments with titanium in the presence of aluminium are shown. Titanium, like silicon (and aluminium), raises the critical points of steel considerably, but, at the same time, it forms carbides stable at very high temperatures.

A micrograph of the fast-cooled sample (Fig. 7, B) shows that all the carbon initially present in the central strip diffused at 950° C. into titanium steel and precipitated there at that temperature in the form of titanium carbides. No uniform distribution of carbon could be reached by diffusion in this case (compare Fig. 4, B and Fig. 7, B) because the tendency for carbon to combine with titanium is so great that diffusion of the carbon into the titanium steel was immediately followed by the precipitation of the stable carbides. These two processes (carbon diffusion and titanium carbide precipitation) continued until there were no free carbon atoms left in solid solution, and, therefore, no carbon rediffusion back to the purer central band could take place in this case (see Fig. 4, C and Fig. 7, C), but persistent carbide segregation was developed.

Now, what is the force that throws carbon atoms, in a slow-cooling piece of steel, from one location to another,

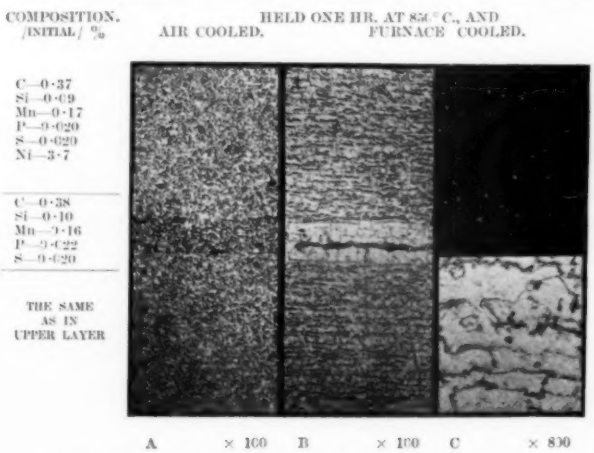


Fig. 6.—Effect of nickel on carbon rediffusion : on slow-cooling carbon migrates to areas rich in nickel. Absence of an eutectoid rim around the ferrite band is due to diffusion of carbon in nickel steel and to the extremely abnormal structure of the latter in this case.

causing its segregation in bands, which are the last to transform ? Evidently, it is the force of rearranging atomic lattices that is responsible. Small carbon atoms being located in interstices of γ-iron lattice can move rather freely and, after a comparatively short period of time at a suitable temperature, come to a rather uniform distribution between adjacent areas of solid solution.

[5] A suggestion that it is local raising of A3 point by phosphorus that causes ferrite banding was first published by H. M. Howe in his book, *The Metallography of Steel and Cast Iron*, p. 561 (1916).

But much bigger atoms of silicon, manganese, nickel and many other elements go into solid solution by substituting iron atoms in the lattice and, being very slow to diffuse, cause persistent dendritic segregation. Hot-work deforms dendrites and produces primary banding. Bands, different in composition, have different critical ranges and rates of

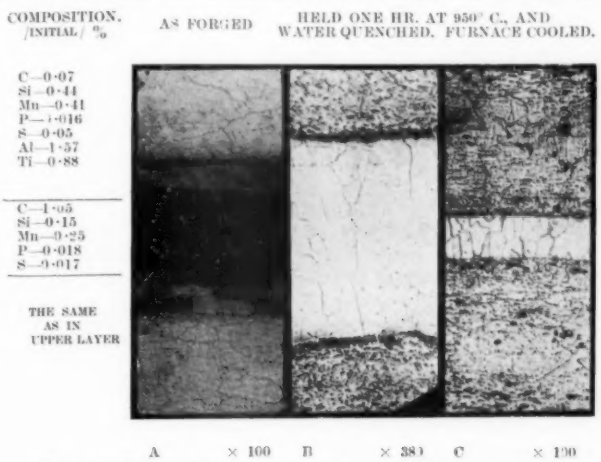


Fig. 7.—Effect of titanum on carbon rediffusion : carbon diffusion at high temperatures is accompanied by precipitation of very stable titanium carbides, thus excluding the possibility of carbon rediffusion on subsequent slow cooling.

$\gamma \rightarrow \alpha$ transformation in spite of a rather uniform carbon concentration (after soaking sufficient time at some temperature above A_3 point). Carbon solubility in α-iron is very low, and after beginning of $\gamma \rightarrow \alpha$ transformation in bands having higher A_3 point, carbon is forced out of them and migrates into other bands which still remain in the austenitic condition, and can dissolve more of this element. Ferrite and pearlite bands are thus formed on slow cooling. Carbon rediffusion is a time-taking process and can be prevented by sufficiently rapid cooling through the critical range, but its cause —primary banding—is not affected by this treatment, and can be revealed by etching with a copper reagent.

The same process of carbon rediffusion is also responsible for formation of ferrite and pearlite grains seen in a transverse section of a hot-worked bar, as far as these grains represent cross-sections of ferrite and pearlite bands. The size and arrangement of ferrite and pearlite areas both in longitudinal and transverse sections of a hot-worked bar thus depend on size and the composition of primary bands, and on the rate of cooling.

Inert non-metallic inclusions (that are not able to dissociate in a solid steel and contaminate it with some elements) which segregate in inter-dendritic spaces (together with other impurities and alloying elements) probably do not exert any influence on the process of carbon rediffusion ; their occurrece in ferrite or pearlite bands is determined by the summary effect of other segregates on the critical points of steel. Thus, if interdendritic spaces are rich in elements that raise the critical points (such as phosphorus, silicon, etc.) inclusions are found in ferrite bands ; but if the main segregate is an element that lowers the critical points (such as manganese) they are located in pearlite bands (as shown in Fig. 3).

Future investigations are necessary to show why carbon rediffusion behaves differently and why ferrite banding does not appear when very large austenitic grains are present in a slow-cooling piece of steel.

In conclusion, on the basis of the results of the present investigation and of some practical observations, it may be suggested that ferrite banding may be to a considerable extent prevented, and the directional effect of primary banding on the physical properties reduced by balancing the composition of a steel so that alloying elements which segregate in interdendritic spaces would oppose each other in their influence on the direction of carbon rediffusion (as is the case with some Si-Mn steels).

Reviews of Current Literature

The Structure of Metals and Alloys

This is the first of a series of Reports and Monographs which has been commenced by the Institute of Metals, the object of which is to reveiw progress in metallurgy. The Institute has chosen a very difficult task, because metallurgy is still very largely an experimental science, but there is no doubt metallurgists and engineers will welcome clear and concise information on many aspects of metallurgy by recognised authorities.

This first monograph is by Dr. Hume-Rothery, who is a distinguished worker and recognised authority on the structure of metals and alloys. It reviews much of the important work done in this field during the last 15 years—not a complete summary but a selection of certain subjects which appear to throw light on the fundamental principles. For instance, sections are devoted to the electronic background of metallurgy, the crystal structure of the elements, atomic radii of the elements, primary metallic solid solutions, intermediate phases in alloy systems, and imperfections in crystals. These fairly round off the subject. Each chapter is provided with a bibliography of carefully-selected, selected references—the wheat has been winnowed from the chaff. An adequate index is provided, and the whole is enclosed in a limp linen cover.

In the last 15 years there has been a continual increase in the published work dealing with the crystal structure of metals and alloys. The rapid development of this subject has coincided with two further advances of outstanding importance. In the first place there has been a considerable improvement in the experimental methods for determining equilibrium diagrams, with the result that in several cases these diagrams, or at least some parts of them, are known with sufficient accuracy to justify detailed comparison and theoretical investigation. In the second place there has been revolutionary changes in the modern physical theory of electrons and atomic structure, and the new theories have been applied directly to the properties of metallic crystals. The present period is thus one of immense interest, when some of the fundamental principles underlying alloy structures are becoming clear, and if these principles can be appreciated the possibilities of their practical application are considerable. This review goes far in assisting the reader towards a proper appreciation of the fundamental principles associated with the structure of metals and alloys.

The subject is presented in a lucid and informative manner, and this book cannot fail to hold the interest of those who are seeking reliable information on the structure of metals. So few text-books attempt to show the principles underlying equilibrium diagrams that this book has a special value since particular attention is given to this subject. If this book is representative of the Reports and Monographs to be issued by the Institute of Metals, all who are seeking fuller information on metals and alloys will be indebted to the Institute, certainly this one is a valuable work.

By William Hume-Rothery. Demy 8 vo, pp. 120, with 61 illustrations; Published by the Institute of Metals, 36, Victoria Street, London, S.W. 1, price, 3s. 6d. post free.

Through the co-operation of the American Electro-Platers' Society and the American Society for Testing Materials, there has been issued in a special pamphlet, three new specifications covering electro-deposited coatings of zinc, cadmium, nickel and chromium on steel. These were dveloped by the two societies and the National Bureau of Standards. Copies can be obtained from the A.E.S., 90, Maynard Street, Springfield, Mass., or A.S.T.M., 260, S. Broad Street, Philadelphia, at 25 cents per copy; in lots of 10 to 24 copies, 20 cents each, and with increasing quantities further price reductions are made.

Tin Researches

Further researches by the International Tin Research and Development Council are contained in papers recently published. These are Technical Publications Series A, Nos. 31, 32 and 33. No. 31 is by Professor D. Hanson and Mr. W. T. Pell-Walpole and deals with "The Constitution of the Tin-Rich Antimony-Tin Alloys"; No. 32 describes Dr. W. D. Jones' investigations on the "Influence of Surface Inclusions on the Porosity of Hot-Tinned Coatings on Copper"; and No. 33 describes Mr. E. J. Daniel's experiments on the "Hot-Tinning of Copper: The Attack on the Base Metal and its Effects."

The Solubility of Antimony in Tin

In this study a range of alloys containing from 2–14% antimony were prepared by melting tin under charcoal and adding the antimony in the form of a temper alloy consisting of 50% each of pure antimony and tin. Thermal analysis, microscopical analysis and measurement of electrical resistivity were used to determine the constitution of the alloys. The alloys were examined after the following treatments: (1) chill-cast (2) annealed for four weeks at 190° C. and cooled in the furnace (3) quenched from 190° C. (4) as (3), but then tempered for one hour at 100° C. (5) quenched at temperatures between 190° C. and 245° C.

The solubility of antimony in tin is shown to decrease from 10·5% at 246° C. to 4% at 190° C. and to 3–5% at 100° C. The form of the solubility curves suggests that the mechanical properties of some of the tin-rich bearing metals might be sensitive to heat-treatment and further researches are proceeding in this direction.

Hot-Tinning of Copper

The investigations by Dr. Jones deal with one of the most important causes of porosity. Preliminary tests indicated that the production of porous, irregular tin coatings on copper during hot-tinning is associated with the presence of inclusions of cuprous oxide in the copper base, and that relatively non-porous smooth coatings are produced in the absence of such inclusions. The presence of cuprous oxide inclusions can be readily detected by amalgamation of the copper surface at room temperature by the use of acid mercuric chloride.

Copper containing oxide inclusions can be made to give non-porous smooth coatings by certain special pre-treatments which reduce the cuprous oxide to metal Thus, the copper may be simply immersed for some minutes in cold hypophosphorous acid (2–50%) or treated cathodically in dilute caustic soda solution, the latter process being the more satisfactory.

Smooth tin coatings are readily obtained on oxygen-free copper in the absence of any special pre-treatment, and this material is recommended as the most suitable for hot-tinning. This is consistent with the view that cuprous oxide inclusions in other types of copper are a major cause of the production of irregular, highly porous coatings.

In Mr. Daniel's study, examination of cross sections of tinned and soldered coatings on copper shows that there is always Cu_3Sn in contact with the copper and a layer of Cu_6Sn_5 over it. This duplex layer tends to detach in fragments as it is formed, leading to contamination of the tin in the bath and the coating. The effect of this copper contamination on the irregular coatings typical of those on copper containing cuprous oxide inclusions, is beneficial up to about 1%, due, it is thought, to the compound particles anchoring the liquid tin on the surface of the copper. This is in accordance with the fact that deliberate addition of copper to fresh tinning baths is common works practice. Excess of copper leads to rought coatings. Tests were made on ordinary copper and on oxygen-free copper.

Copies of the above publications may be obtained free of charge from the International Tin Research and Development Council, Manfield House, 378, Strand, London, W.C. 2.

The Upper and Lower Yield Points and the Breaking Strain

By Prof. Dr. G. WELTER.

Further to research on the upper and lower yield limits a few points are considered on the basis of tests which may influence the results obtained by the usual and direct weight loading. It has been found that the test speed in the ordinary tensile test lies considerably higher within the yield point range than in the direct weight loading test. Having regard to the manner of loading, the machines were divided into three main groups (positively rigid, positively flexible, and direct free loading), which are discussed successively in their effect upon the results of the tensile test. The transmission ratio between measuring clamping head and diagram deflection—i.e., the manner of action, differs with the various types of machines. The ratio should preferably be low in order to obtain a true reproduction of the properties of the material. By means of a device which permits of artificial simulation of an upper and lower yield point the behaviour of the various kinds of loading is recorded in diagrams, thereby obtaining perfectly similar results to those available for the yield limit of mild steel under various kinds of loading. It is concluded that the upper yield point is not contingent on the material, but merely a question of how the test is performed, and of the type of testing machine used.

ON the basis of the research on yield limits and the tensile strength of mild steel and other metals[1], a few factors are considered more fully which are likely to have influence upon the test results. When making tensile tests, for instance, it is known that the deformation speed influences the test results, that is, the diagram. In a test with direct weight-loading, for example, if the deformation speeds at the yield limit and during contraction are exceedingly great, they might react upon the test results in such a way that the various specific loadings would lie higher than in a standard tensile test.

It is proposed to discuss methods of loading and loading speeds in various potential applications of tensile tests. In so doing, it is necessary to ascertain clearly how the strain-path diagrams will turn out with the various kinds of loading. In this respect, the testing machines may be classified, according to the manner of loading, into three main groups—viz., (1) machines with positively-rigid loading device, (2) machines with positively-flexible loading device, (3) machines with free loading.

In the first group are the machines used in most laboratories. These machines generally show a very high transmission ratio (multiple lever scales, measuring cylinders, pendulum pressure gauge, etc.) between the path distance of the clamping head and the load indication on the dynamometer or in the diagram. The reaction of a movement of this clamping head upon the load indication in the diagram is very considerable with the majority of machines in this group under more than a few tons of load. This group should also be deemed to include the machines, more rarely encountered, with low test load, showing a smaller transmission ratio, as with wire and sheet-testing machine (single direct-beam transmission).

The machines within the second and third groups are not usually seen among the ordinary laboratory machines, although they represent those types which most closely approach the conditions of really true reproduction of the strain-path diagram. These methods of loading are discussed from test results with yield limits produced artificially by means of two sliding links clamped one upon the other. Apart from the static tensile test, however, it is proved by means of other test methods that the phenomena of an upper or lower yield limit of mild steel is not recorded by a dynamic tensile test, nor by a static bending test.

Fig. 1.

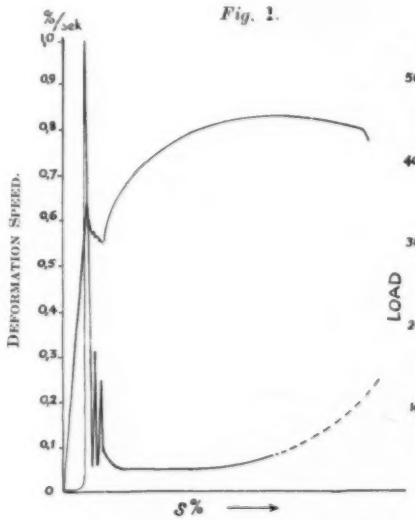
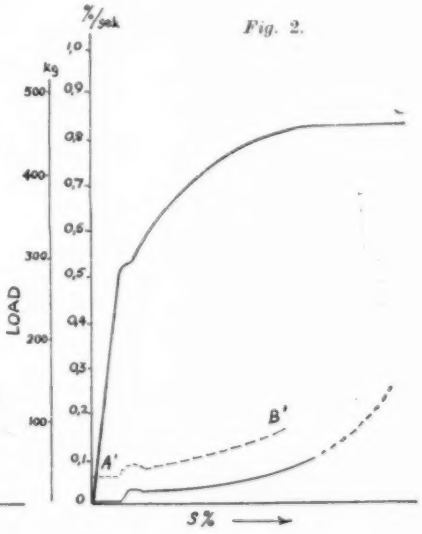


Fig. 2.



Influence of Deformation Speed

As the deformation speed is likely to influence the yield resistance, since high yielding speeds of the test bar will entail a higher resistance to deformation, this point was investigated more closely. Bearing in mind that the test bar is examined in the usual tensile test with gradually-increasing elongation, that is, at approximately constant deformation speed, while in the event of direct weight loading a free yielding prevails, allowing a rising yield speed to develop, these conditions were checked up on test bars of mild steel, on the one hand under customary test conditions, and on the other hand under direct weight loading, and evaluated by calculation. Fig. 1 reproduces the usual tensile diagram for mild steel, in which the deformation speed in the various yield ranges is shown separately in the form of curves. The machine on which these tests were carried out (Amsler Type 5 ZD.181),

[1] Welter, *Metallurgia*, vol. 13, No. 75, pp. 89–92. See also Späth, "Influence of Resilience Within Tensile Machine Upon the Tension-elongation Diagram," *Archiv für das Eisenhüttenwesen*, 1935, No. 6, p. 277.

showed an elongation speed of approximately 0·06% per sec., so that the tensile test on a steel sample of approximately 18% elongation lasted approximately 5 mins. The deformation speeds at the yield limit were determined by the strain-path diagram as per Fig. 7 of our original work, according to which the variation in the length of the test bar can be calculated between the upper and lower yield point from the drop in load. It is evident

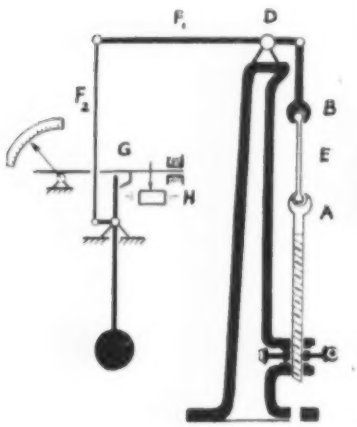


Fig. 3a.

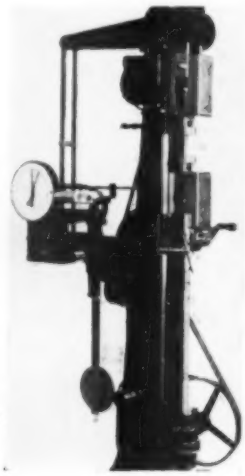


Fig. 3b.

from Fig. 1 that the yield speed in the usual tensile test at the beginning of the yield limit at the moment of load decrease is by no means so negligible as is frequently taken for granted. On the contrary, it amounts to an appreciable value. With a load drop at the yield limit as determined in these tests, of approximately 30 kilos, which occurs in approximately ½ sec., this tallies with an original elongation speed of the test bar of approximately 1% elongation per sec. For the minimum deformation speed of the machine of approximately 0·06% per sec., this corresponds to approximately 20 times higher value than the elongation speed at which the machine operates. This process repeats itself again several times after the first comparatively high yield speed as the load decreases from the upper to the lower yield limit, until the load rises uniformly; the course of this diagram within the ambit of the yield limit is of a zig-zag nature and perfectly irregular.

Furthermore, the deformation speed after exceeding the maximum load limit does not tally with the rate of 0·06% per sec. as determined by the machine. With normal tensile tests as well, a multiple increase of yield speed occurs in the test bar towards the end of the test, which very materially exceeds the speed positively impressed upon the bar by the machine. All testers of materials know that in standard tensile tests of steel, for example, after the beginning of local contraction the break of the test-piece will usually occur immediately afterwards. The speed in the yield cone is so considerable that it is hardly possible to follow up the individual phases of the breaking process. To the uniform speed of the loading clamping head of the machine should be added, in connection with the load drop due to contraction, the motion of the measuring clamping head due to the return of the strain indicator; also the reaction of the machine-frame, deformed highly flexibly under heavy load, as also of the clamping devices, become clearly noticeable at this moment in the sense of enhanced yielding speed. As the test bar in this stage expands locally over a very short distance (only a few millimetres of elongation path, according to material and section) these factors cause an instantaneous break, that is to say, they bring about a very high deformation speed of the test bar prior to fracture. The curve of deformation speeds will therefore show in the usual tensile test, as per Fig. 1, high values not only in the vicinity of the yield limit, but also at the end of the diagram shortly before breaking. Only in the case of very plastic materials with distinct local deformation, is the material in the yielding cone able to compensate the additional paths attributable to the machine, and to extend, as tests have shown, under gradually declining load in the same measure as the clamping head driven by the machine. In so doing, an utterly unnatural strain-path diagram will be recorded by the machine after exceeding the maximum load limit.

In Fig. 2 are reproduced two test results with direct weight loading, carried out at different elongation speeds. The test duration was 5 mins. and 30 mins. The strain-elongation diagram is plotted as recorded by the machine (only the elongation scale has been reproduced magnified twice with regard to Fig. 1). It is noticeable that the two tensile diagrams, which are almost identical for a test duration of 5 mins. and 30 mins., tally almost completely with the diagram No. 2, reproduced in the main work, Fig. 8. The deformation speeds at the yield limit determined in this text in many figures amounted to approximately 0·03% elongation per sec., and to approximately 0·02 to 0·1% per sec. in the further course between the end of the yield limit until in the vicinity of the maximum load limit. Consequently, there exists a ratio of approximately 1 : 1·5 between the maximum yielding speed at the yield limit and the remaining track of the diagram between yield limit and the beginning of the higher loading stages, as shown in Fig. 2, and this ratio remains about the same for tests of a duration of approximately 5 mins. (A′–B′). After passing the maximum load limit, the deformation speeds gradually increase, and just prior to breaking, they reach a value which is hardly likely to exceed the elongation speeds in the usual tensile test, Fig. 1, as has been shown by test results with mild steel. On carrying out the test during a period of 5 mins., the deformation speeds are correspondingly higher (A′–B′) Fig. 2, at the yield limit, while at the breaking limit they do not in principle adopt any materially different course than with the usual tensile test. It will thus follow that test speeds which occur under

Fig. 4.

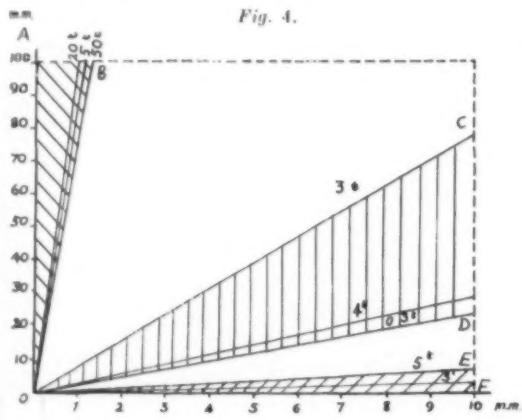


Fig. 5a.

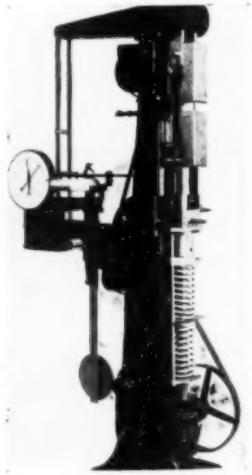


Fig. 5b.

direct weight loading in no case exceed 0·5 to 0·6% elongation per sec., even in a test of only 5 mins. duration.

With reference to test results by other workers, and on the basis of more recent tests carried out by Oknowski and myself, at the yield speed of 0·5% to 0·6% elongation per sec. no evidence was discernible of the influence upon the yield resistance of mild steel. According to Körber,[2] an influence of the deformation speed upon the yield limit, for example, was traced only at exceedingly high test velocities. At a 20 times greater loading speed (0·8 kg./per sq. mm., as against 0·04 kg./sq. mm. per sec.), compared with normal, a slight increase in strength expressible in figures was determined by tests. Similarly, it has been ascertained by Oknowski and myself[3] that the yield limit of mild steel is increased by approximately 0·4 to 0·5 kg./sq. mm., that is, by only approximately 1·5 to 2% when the percentage elongation per sec. is raised from approximately 0·095 to 0·56%—*i.e.*, by five to six times. Similarly, the tensile strength also at similar deformation speeds of maximum 0·56% elongation per sec. are hardly appreciably enhanced (by only approximately 0·65 kg./sq. mm.).

It is thus manifest from the investigations under review that in the test involving direct weight loading deformation speeds arise which are below those values which entail an appreciable increase in yield limit and breaking strength. Thus, the rising load recording under free weight loading at the yield limit or at the maximum load limit can not be explained by the influence of the deformation speed upon the increase in yield resistance. Beyond this, moreover, it would not be comprehensible that the greater yield speed accidentally arising should cause just such an increase in yield resistance as to record a uniform, steadily ascending strain-path diagram both in the range of yield limit and also at the maximum load limit.

Loading and Elongation Speed

The various methods of loading in resistance tests may be sub-divided into three main groups, as already mentioned. The machines used for tensile tests at the present day fall into the first section, which we will deal with more fully.

(*a*) *Positively Rigid Loading.*—In standard tensile tests the test bar is clamped between two clamping heads, A and B, which in turn are incorporated positively and perfectly rigidly in a frame C, which absorbs the comparatively high loads on the test bar E, Figs. 3a and 3b. The load upon the test-piece is produced, through the intermediary of the clamping head, A, by means of mechanical (spindle and wormwheel), or hydraulic devices (cylinder and piston), maintained rigidly by the machine frame C. The second clamping head B transmits the load, also utterly inflexibly, on the one hand to the frame by means of a supporting point D, while serving on the other hand to determine the particular load acting upon the test-piece. The indication of the force is also effected by mechanical means due to a system of lever and rods (F_1, F_2, G), sliding weight, or the like, or hydraulically by measuring cylinders (gauge cylinder, cylinder with pendulum pressure gauge, etc.) All parts of the test machine, including frame and clamping head with suspension and levers, are designed to eliminate all flexible yielding as far as possible. The loading with this kind of machine is thus ensured perfectly, positively and inflexibly, while the loading speed, and thus the elongation speed, of the test bar is produced uniformly by the loading device. The transmission ratio of the usual tensile machines, *i.e.*, the path distance of the clamping head B serving for load indication in mm., relatively to the dynamometer indication or the deflection on the diagram drum H in mm. is ordinarily very great. As shown by a few figures in Table 1, which were obtained from a few available machines, this ratio moves between 1—79 to 1—100 for the normal types of machines for maximum loads of approximately over five tons, whereas, it is only with small types of machines for low loads, that these figures are in such proportion, for instance, as 1—2·5 to 1—7·8, due to single leverage.

According to Fig. 4, the transmission ratios for the majority of tensile machines of a capacity exceeding, say,

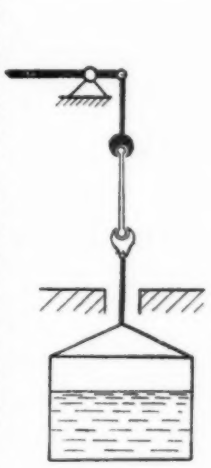


Fig. 8a.

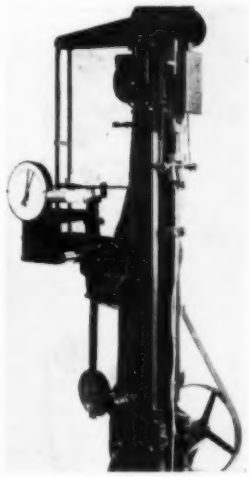


Fig. 8b.

TABLE I.

No.	Type. Ton. Max.	Type. Load. Dyn. kg.	Loading.	Transmission to dynamo.	Ratio.* a.	Ratio.* b.	Comments.
1	0·3	100	Mechanical	Mechanical	1–2·5	1–2·5	—
2	4	400	Hydraulic	Hydraulic	1–11·2	1–2·8	—
3	5	1,000	,,	,,	1–78·2	1–7·8	—
4	5	500	Mechanical	Mechanical	1–423	1–84·7	—
5	20	2,000	Hydraulic	Hydraulic	1–2000	1–100	—
6	50	10,000	,,	Mechanical	1–7300	1–79	—
4a	5	500	Mechanical	Mechanical	1–3	1–0·6	with single set of springs.
4b	5	500	Mechanical	Mechanical	1–1·5	1–0·3	with double set of springs.

* Path distance of measuring clamping head.
a For dynamometer indication in kilos.
b For diagram track in mm.

Fig. 6a

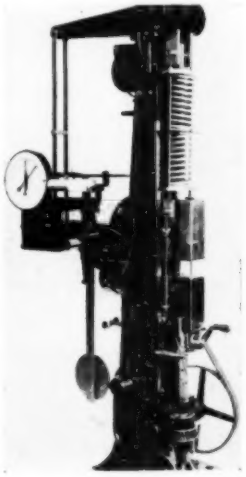


Fig. 6b.

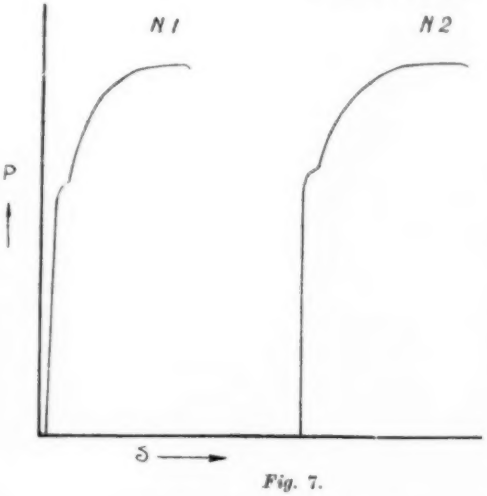


Fig. 7.

[2] L. Körber, "The Yield Limit as a Basis for Quality and Acceptance Tests," *Communications D.V.M.T.*, No. 8, 1926.

[3] L. Welter u. L. Oknowski, "Wiadomosci Instytutu Metalurgij i Metaloznawstwa Politechnikl Warszawskiej," *Rok* 2, Nr. 1, str. 21 (Tab. V. Versuchs N. 4–7 Zeit. 1' 4" + 25").

five tons, may be incorporated in the shaded field O-A-B, wherein O-A represents the maximum diagram length, and A-B the path of the measuring clamping head. The machines for small loads are included within the area O-C-D with respect to their ratio of transmission.

(*b*) *Positive-flexible Loading and Elongation Speed.*—This kind of loading can be provided on existent machines without material alterations. By interposing a steel spring for instance, between clamping head and frame of the machine, Figs. 5a, 5b, and 6a, 6b, the working conditions of the test machines may be varied fundamentally to such an extent that the results obtained will approach reality by a very considerable amount. With a constant leverage between measuring clamping head and diagram track of the machine, under otherwise identical test conditions, really true indications are obtained by the machine, as far as the yield point is concerned. As has been shown by tests, if a steel spring (or hydraulic cylinder with air cushion) of but 80 to 90 mm. maximum stroke is interposed, the load indication at the yield limit will no longer decline when the steel elongates comparatively quicker. No upper or lower yield limit occurs, but the diagram shows steadily rising load path curve in which the direction at the yield limit only varies due to accelerated yielding. Owing to the interposition of a flexible element the rigidity of the machine is removed, and any sudden elongation of the test bar is compensated by the spring, without the dynamometer reacting thereto by heavy load drop. The machine for five-ton capacity is given in this way, for example, an entirely different transmission ratio. If two springs are inserted with a maximum stroke of 180 mm. it will be approximately 1—0·3, and will be situated in the lower area O-E-F, Fig. 4.

It should be immaterial whether these springs are located between the loading clamping head and the machine body (Fig. 5a, 5b), or between the measuring clamping head and indicating dynamometer (Fig. 6a, 6b). The results will be roughly the same with both methods, that is, in each instance no decrease in load will be recorded at the yield limit of mild steel, and after passing the maximum load limit the drop in load will be only insignificant, according to the stroke of the spring (Fig. 7, diagram No. 1 for machine 5a, 5b; and diagram No. 2 for machine 6a, 6b); this is discussed in further experimental work.

(*c*) *Unrestrained, Natural Loading.*—The most natural and obvious course of loading in tensile tests is undoubtedly the direct, unrestrained weight loading of the test bar. Tests carried out under such circumstances should supply the clearest conditions obtainable with this kind of test; the results should be free from incidental influences and obstructions, as is the case with positive-rigid loading. The author is not aware of any other viewpoints prevailing in the choice of the positive-rigid manner of loading, apart from requirements of design with a view to controlling the heavy loads obtaining. Circumstances are not likely to arise which call for "positive" elongation of the material as a condition. The supreme rule which may govern the manner of loading is the requirements generally admitted in testing of materials, that all tests should, as far as possible, be carried out so that the test conditions will most closely approximate the conditions obtaining in practice. Under this viewpoint direct, unrestrained weight loading should be the only correct method of loading, permitting of positive conclusions as to the actual behaviour of the material in practical use.

The testing machine must furnish a true picture of the loading-elongation conditions of the materials which shall come as close as possible to the results obtained by direct weight loading. A great portion of the machinery is stressed in practice by direct weight loading, which, in most cases is free to exert itself. This is the case, for example, with haulage ropes, cables, and rods of suspension bridges, plain, supported, free joists, rods for the transmission of power in prime movers (piston rod, connecting-rod, etc.). These elements are all able to yield under the tensile, compression or bending strains, without being impeded by positive incidental stresses.

Direct free weight-loading as diagrammatically indicated in Fig. 8a and 8b, is perfectly free from the serious disadvantages of positive-rigid loading as previously laid down. The direct weight load (water-tank) was attached to the tensile machine without further alterations by means of cables in the floor below. The device with direct weight load represents the ideal case, in which no reaction can occur between the elongation of the test-pieces upon the indication of force applied. The slowly and gradually rising load is freely suspended, with the test-piece, from the power-indicating device. It therefore cannot possibly exert any untoward influence, providing that elongation does not take place suddenly and cause a load drop on the strain indicator. Neither is it conceivable that the flexible bending of the machine frame should in any way influence, say, the test bar suspended by one point together with its load, or entail any untoward reaction upon the diagram. The indication of strain, irrespective of a plain lever transmission, a measuring cylinder or pendulum pressure gauge, will remain utterly unaffected by the yielding process in the test-piece or by the elongation speed of the loading tension head. Whether dealing with a great or small elongation velocity, no reaction is possible upon the strain indicated in the diagram (excepting if the test bar were partly to relieve itself by a sudden, spontaneous elongation). This system is in equilibrium through the entire test duration, since the loading balances the deflection by the dynamometer. The load is on the one hand recorded perfectly by the dynamometer without interference, while the elongation of the test bar is also transferred to the diagram without ancilliary influences and without distortion; each phase of the tension-elongation progress is, in this manner, a true reproduction. Accordingly, the progress of the force in the diagram shows no declining tendency in the neighbourhood of the upper yield limit with this loading.

A steadily-rising tension-elongation curve is recorded, which, in the vicinity of the yield limit, exhibits accelerated yielding (diagram similar to Fig. 7 Nos. 1 and 2). Even in the case of mild iron bar were completely to release the load due to yielding between the upper and lower yield limit for a brief space of time in reality, as should be inferred from the usual diagram, this process would also have to be recorded by direct loading as is demonstrated in the following section. Furthermore, direct weight loading reproduces the correct, unfalsified conditions even under the heading of contraction of the material. It is not a matter of an artificially-forced diagram, which would allow of drawing no conclusions as to the real behaviour of the material.

Influence of the Test Character upon the Test Results

In order to clear up the question of the upper and lower yield limit, it will further be of interest briefly to enter into the nature of the tests and their influence upon the results.

If the yield limit with upper and lower yielding point is a matter of a genuine, characteristic property of the material, which is independent of the manner of testing, it should be proved inequivocally by all kinds of tests, irrespective of the manner of loading. As has been shown by a few informatory tests in this connection, a steadily-progressing line was obtained at the yield limit also in static bending tests, which showed a change in direction due to accelerated yielding, thus tallying with the diagram obtained by direct, free weight loading. At other deformation speeds, on the other hand, a distinct upper and lower yield limit was obtained in static bending tests also due to acceleration and retardation of the pendulum mass, as is recorded in normal tensile tests. It should also be pointed out that an upper and lower yield limit does not arise in dynamic tensile tests.[4]

[4] Cf. G. Welter, Zft. f. *Metallkunde*, No. 4. 1935. P. 113.

Artificial Production of Upper and Lower Yield Limit

By way of concluding these test series, the upper and lower yield limit was artificially produced on the machine, and positive, rigid loading, by means of an extremely simple device, and reproduced also with positive-flexible and unrestrained free loading. In case the upper and lower yield limit is a property, which actually has nothing in common with the way in which the test is carried out, this quality should invariably be recorded, irrespective of the manner of loading, providing the loading so permits. As this might be doubted, both in positive-flexible loading and also in unrestrained, free loading, tests were carried out with an artificially-produced upper and lower yield limit. As will be seen from Fig. 9, a plain device was employed, based on the sliding of two flat irons, A and B in the form of a strap or link, held together by a screw. In order to remove the resistance as completely as possible after the first slip, the sliding surfaces are somewhat tapered, so that, after the slightest motion the sliding resistance will instantaneously drop to zero. The path of travel of the two flats, one relatively to the other, before the load rises again (by placing the screwed bolt C at the end of the slot D), may be adjusted as desired within a few tenths of a millimetre up to approximately 5 mm. A rubber cushion is provided at E, so that the impact of the entire load slipped off shall not produce any hard shock. According to how tightly the screw C is screwed home, the altitude level of the upper yield limit in the diagram may be varied within a few kilos or several hundred kilos. In the tests under consideration loads were chosen which tallied in all cases approximately with those of the tested mild steel (*i.e.*, approximately 250 kilos to 300 kilos) at the yield limit. The test results obtained by this device for artificial production of the upper and lower yield limit are reproduced in Fig. 10 for the usual testing machines (positive-rigid loading), as also for loading of positive-flexible and free, unrestrained load effect.

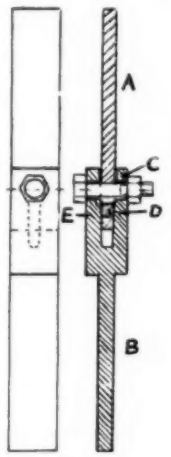


Fig. 9.

The Upper and Lower Yield Points and the Breaking Strain

All these tests show that the characteristic upper and lower yield limit arising with mild steel may be perfectly imitated artificially by means of this device. According to diagram No. 1, Fig. 10, a uniform, rising load reaches an upper load limit, followed by a steep decline in load. This drop may be selected, according to the adjustment of the gap in the slot D of the device shown in Fig. 9, in any magnitude desired. In this test, the clearance was less than about 1 mm. It may be mentioned that these diagrams were obtained with the five-ton Amsler machine 5 ZD.181, with positively-rigid loading, which was also used for the tests in the principal work. At a rapid elongation speed, produced by the hand-crank for the adjustment of the lower clamping head (approximately 10 mm. per sec.), diagram No. 2 was obtained on the same machine with the same strain indicator. This diagram is perfectly similar to that for mild steel obtained by direct weight loading.

By carrying out the test with the artificial yield limit on the small tensile machine (Amsler 0·5 Z. 44) with small transmission ratio, diagram No. 3 was obtained, by loading the test-pieces slowly (1 mm. per sec.) ; an upper and lower yield limit arose which, owing to the fairly small transmission ratio between clamping head and diagram cylinder, did not decline vertically, but recorded an elongation, down to a lower limit value, whereupon the load began to rise again. If this test is carried out more rapidly (approximately 10 mm. per sec.), Diagram No. 4 will be recorded, which fully tallies with that of soft steel, which, however, was tested on this machine at a much smaller elongation speed (cf. diagram No. 3, Fig. 8 of the main work). According to the loading speed the slope angle of the section A-B turns out greater or lesser.

Now, if the loading of the device for producing an artificial yield point is carried out on a machine with positive-flexible loading in accordance with the method previously discussed, that is, on the five-ton Amsler machine with interposition of a helical spring Fig. 5a, Diagram No. 5, Fig. 10, will be obtained which also does not show any upper or lower load limit within the vicinity of accelerated elongation, but a progressively rising load with a change in the direction of the strain-path diagram in the yielding range.

In order further to show that even with direct, unrestrained free weight loading a drop is possible from an upper to a lower load, if the material actually elongates spontaneously of its own accord with attendant reduction in load, as might be inferred from the diagram for mild steel, from the usual machines, a further test was carried out by means of the artificial yield-limit apparatus with direct weight loading. As was to be expected, a load drop is again recorded in the diagram which, although clearly marked, is yet appreciably smaller in extent, owing to the relief operating for exceedingly short time, than with the machine comprising a positive-rigid loading (Fig. 10, No. 6). The material point, however, is that a drop in load, if actually existant, should be automatically recorded in the diagram by the machine even in the event of direct weight loading. With a slip path in the slot of approximately 5 mm., this load drop amounted to approximately eight to 10 kilos at 360 kilos. However, if the dynamometer mass should be unable to follow a drop in such brief time, a parallel path or distance should arise at the yield limit, but never a steadily-rising load-path curve, as is the case in the test with mild steel.

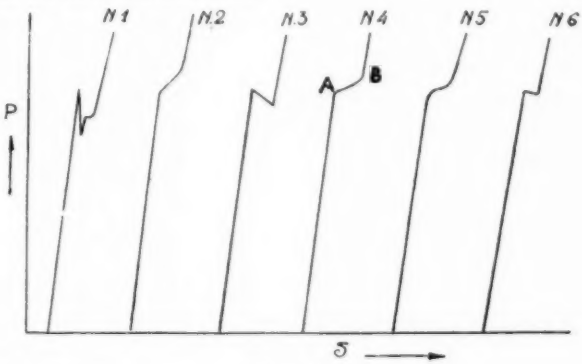


Fig. 10.

Conclusions

It is manifest from the tests under consideration that the occurrence of an upper and lower yield limit is merely a matter of test performance and test machine. There is no upper or lower yield limit, either in connection with mild steel or other metals and all theoretical hypotheses to explain the drop in load at the yield limit are untenable. The upper yield limit is not contingent on the material, as assumed by most research workers. It is merely to be attributed to the loading mechanism as also to the loading and strain measuring device of the test machine, and has nothing in common with a characteristic property of the material tested. Solely an accelerated yielding of the material takes place at the yield limit, due to which no drop is caused in the load from an upper to a lower load stage of the test bar.

Similarly, the decline in loading from the maximum load to the breaking load on the material is a matter of a peculiarity of the machine, according to which the actual conditions obtaining in the tensile test are not reproduced true to reality.

Note.—The work was carried out in the Laboratory of the Faculty for Metallurgy and Metallography of the Warsaw Technical High School.

The Temperature Difference Method of Open-Hearth Furnace Reversal

By A. SMITHSON

Although a comparatively recent application, it has been proved that automatic control of the reversals of an open-hearth furnace improves the furnace efficiency. The following article compares the respective merits of the systems which are in use, and describes one of the most successful.

IT is universally agreed that reversal of an open-hearth furnace on an empirical time-cycle basis is fundamentally unsound, but opinion is divided on the respective merits of manual reversal in accordance with automatically operated signals and fully automatic reversal. The semi-automatic and fully-automatic systems, as they are called, only differ in the method of operation of the reversal valve and air slides. In the former, the reversal is carried out manually, while in the latter, reversal is effected by auxiliary equipment operated by the control instrument.

The operation of both systems depends on the temperature difference between the air flues of the furnace—*i.e.*, one passing the ingoing air, and the other the waste products of combustion. Clearly, this means control of the reversals on one only of the many variable factors in evidence. It is impossible to correlate all of them, but as temperature is the most important, the system is an efficient compromise.

Some heats may be automatically controlled throughout, but such cases are exceptional. Generally, it is necessary at times in a heat to delay or speed up reversal to correct some undesirable condition in the furnace bath. At such times the control equipment must be ignored, and so, in effect, the fully-automatic system becomes semi-automatic.

To ignore the signals in the semi-automatic system is simple. In the fully-automatic system push-button controls are generally provided for such emergencies. This is a clear indication that the reversals cannot be automatically controlled entirely, and an admission of the partial failure of this system. Push-button controls are an additional complication to an already complicated system—electric, hydraulic or pneumatic equipment is used—and obviously the sources of potential trouble are increased. Such equipment is, moreover, expensive, and its maintenance increases the furnace running costs, which are already high.

The actual operation of the reversal valve and air slides in the fully-automatic system means only a slight saving in effort, but in practice this is negligible, and does not warrant the additional expense. It has been claimed that with fully-automatic reversal the time lost in reversing is reduced to a minimum, so that the heat losses by radiation are negligible. This pont has perhaps, been unduly stressed, because even with manual reversal the time taken is short and, in this case also, the heat losses are negligible.

The comparative unimportance of such small losses may be estimated when it is remembered that at each reversal a regenerator full of preheated gas and one of preheated air are lost. This probably forms the largest proportion of the heat lost from the furnace, and it is, moreover, common to both systems.

To sum up, the semi-automatic system, because of its greater simplicity, lower cost and superior flexibility, would appear to be the more suited to the complex process of steelmaking in the open-hearth furnace, and more likely to find favour in the eyes of discriminating metallurgists and engineers.

The Temperature Difference Method of Open-Hearth Furnace Reversal

Since the auxiliary equipment used for the operation of the valve and air slides in the fully-automatic system is purely mechanical and has no bearing on the technicalities of the system, it is now proposed to deal fully with the semi-automatic system.

As mentioned above, the system bases its operation on a temperature difference indicated by two thermo-couples connected in opposition, suitably located in the air flues just outside the cold end of the chequer work. This temperature difference is impressed on a control instrument which lights a warning lamp and sounds a loud horn when a predetermined value has been reached. Reversal is then carried out manually in the usual manner. A record of the temperature at the two chosen points is obtained to serve as a check on the efficiency of operation of the control equipment, and also to assist in determining the temperature difference which gives maximum efficiency.

While several designs of equipment have been evolved especially for this application, the simplest, and probably the most efficient, is one which uses standard industrial instruments. In this design the control instrument used is the standard indicating control pyrometer which has already proved its practical utility for the control of temperature and atmosphere on industrial heat-treatment furnaces. One small modification has been found necessary, namely, calibrating the instrument to read direct in temperature difference from a centre zero.

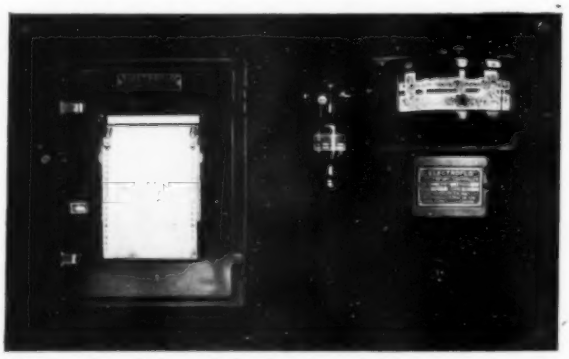


Fig. 1.—A typical panel showing the control pyrometer, recorder and warning lamp and horn.

Since this instrument has only one control index and the temperature difference is alternately negative and positive (due to reversal) a switch to reverse the polarity of the temperature difference e.m.f. is necessary. This is usually automatically operated by the gas or air lever when reversal takes place. The temperature recorder used is the standard industrial instrument, but with increased dotting speed to enable the instrument to follow accurately the rapid temperature fluctuations which occur in the base of the chequers.

It is usual for the control pyrometer, recorder, warning lamp and horn to be mounted on a panel situated at some convenient point on the furnace stage. A typical example of such a panel is shown in Fig. 1. It will be noted from Fig. 2 that double element thermo-couples are used. Thus, the control and recording circuits are entirely separate, so increasing the efficiency of both.

The location of these duplex thermo-couples is important. The positions selected after careful and lengthy investiga-

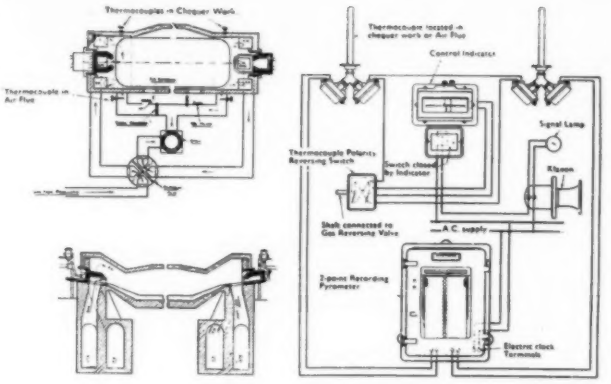


Fig. 2.—Plan view of typical open-hearth furnace, showing the position of the duplex thermo-couples.

tion of chequer conditions are indicated in the plan-view of a typical open-hearth furnace (Fig. 2). As stated previously, these positions are in the air flues, just outside the cold end of the chequer work. The reasons for the selection of these points are as follows :

1. At these points the waste gases are thoroughly mixed, and therefore at a true average temperature. Any temperature fluctuations caused by chemical reactions in the bath have been dissipated in the passage of the gas through the chequer work. It is only when such reactions are excessive that the effect is reflected by an increase in the temperatures of the gases in the flue, and they are then taken into account by the system.
2. The temperatures attained at these points are comparatively low (up to 700 to 800° C.), so that the use of base metal thermo-couples is practicable. These are of a robust character, and will withstand arduous conditions, and give an almost indefinite life.
3. The fluctuations in temperature at these two points due to reversal, are greater than in any other part of the furnace system. This, together with the high e.m.f. developed by base metal thermo-couples enable the temperature difference to be measured with extreme accuracy.
4. Since the temperature—e.m.f. relationship of base metal thermo-couples is practically linear, the control indicator gives *true* temperature difference readings, irrespective of the operating temperatures range of the chequers.

It is frequently considered that the temperature of the thermo-couple on the suction side falls to atmospheric almost immediately after reversal. This may be true if the thermo-couple is at the point of air admission, but in the selected positions a cooling curve with the same characteristic as that of a thermo-couple in the base of the chequers is obtained. It should be borne in mind that just after reversal the thermo-couple is in a hot flue close to the base of the chequers, which are at a temperature of 700 or 800° C. It indicates the actual temperature of the brickwork, and not that of the ingoing air.

When first considering the scheme it may appear that the tops of the chequers are more suitable locations from which to measure the temperature difference. However, the waste gases at these points are at a high temperature —1,350 to 1,400° C.—and subject to temperature fluctuations due to bath reactions. Rare metal thermo-couples or radiation tubes are essential. The former must be protected by impervious refractory sheaths, which are rapidly attacked by dust and oxide particles, and are, moreover, rather fragile.

The temperature difference obtained is smaller than at the bottom of the chequers which, combined with the low temperature e.m.f. characteristics of rare metal thermo-couples, necessitates the use of a control instrument of comparatively low resistance. It is not necessary to point out the respective merits of low and high resistance temperature indicators, since they are common knowledge.

Finally, the temperature—e.m.f. relationship of rare metal thermo-couples—is not linear, so that while the e.m.f. required to operate the control instrument is constant, the temperature difference, measured in degrees, is dependent on the operating temperature range of the chequers.

Radiation tubes are subject to more serious disadvantages than rare-metal thermo-couples. They, of course, obey a fourth power law, and the last disadvantage mentioned for rare-metal thermo-couples is accentuated. It is necessary to sight through windows, requiring a variable correction to the temperature indications, since the windows become dirty. Moreover, the indications obtained are liable to errors due to fumes, for which it is impossible to assess any accurate correction. Radiation tubes do not lend themselves at all well to this special application, and their use should be avoided if at all possible.

The object of the temperature difference method of reversal is frequently obscured by consideration of the actual chequer temperatures and conditions. The reversal system should be devoted to securing the most favourable heat balance in regular service, and this is best accomplished with the thermo-couples in the air flues or towards the bottom of the chequers. The actual temperatures reached at the top of the chequers if required, could be determined by separate radiation pyrometers in the usual manner, the object being to keep watch on the condition of the brickwork. Such considerations, however, should not be allowed to affect the method of applying the reversal system or its efficiency may be impaired.

As mentioned above, the advantages of the use of the temperature difference system of reversal are that a more favourable heat balance is maintained in the furnace melt, and in addition that the maximum quantity of waste heat is returned into the furnace.

The sample chart shown in Fig. 3, which was taken on a furnace actually controlled by the semi-automatic system, will perhaps help to elucidate this latter point. The loss of heat from the furnace is a function of the temperature of the waste gases in the flue, and as this rises the loss rises in proportion. As the chequer brickwork approaches its heat-saturation point, obviously the heat exchange becomes uneconomical, and more and more heat is lost from the furnace. It will be noted from the chart, Fig. 3, that this heat loss is minimised by reversing before the heat saturation point is reached—a condition indicated by excessive retardation in the rate of heating.

Since the heat of the furnace is conserved, the time taken for a heat is slightly reduced, resulting in increased output. While it is difficult to obtain any definite figures for increased output from the limited information available on the few plants in this country equipped with automatic control, it is nevertheless an established fact. In this respect, it is interesting to note that increases of from 10 to 20% in production have been obtained in America where considerably more furnaces are so equipped.

The more favourable heat balance obtained in the furnace is of course reflected in a more uniform quality of steel—a point of considerable importance since rigid specifications both for analysis and physical properties have to be met.

The use of the temperature difference method of reversal has the incidental advantage that the chequers operate between two temperature limits, which are practically constant, as shown by Fig. 3. It is therefore possible to work them at the maximum temperature consistent with safety, and so ensure maximum preheat of the ingoing gas and air. The flame temperature is therefore as high as is possible, so increasing the furnace efficiency, and resulting in saving in fuel. Moreover, the life of the chequer work is prolonged and repairs are required at less frequent intervals, thus lengthening the run of the furnace.

Criticism is always received from the furnace operators of any new equipment, which at first they consider as a

slight on their practical experience. As is usual, the men are not slow to recognise the advantages, and place more and more faith in the equipment as time goes on. The following example clearly indicates this point.

In one of the first plants equipped with semi-automatic reversal in this country the workmen were critical of the new addition. This feeling wore off, and some time later the horn motor failed. A complaint was received from the men to the effect that they could not work the furnace efficiently without the control. This was somewhat surprising, but proved the value of the system.

It is difficult to foresee what the next step towards automatic control will be. When the actual measurement of the temperature of liquid steel has been made practicable further progress may be made. This aspect of the problem is under consideration by the Liquid Steel Temperature Sub-Committee of the Iron and Steel Institute Heterogeneity Committee. So far, the chief retarding factor appears to be the lack of suitable refractory protection for the thermo-couple element, and until this is surmounted no progress on these lines can be made.

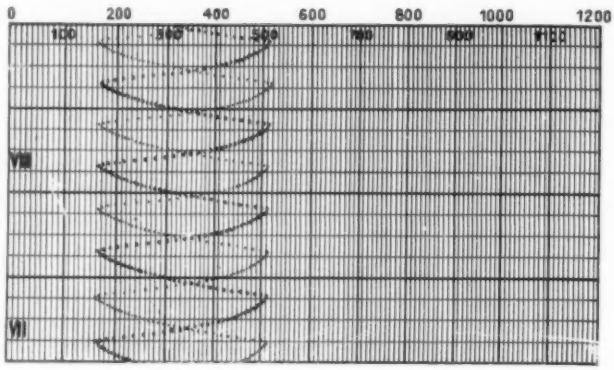


Fig. 3.—Temperature difference chart determining the times of reversals.

Activity at the Darlington Forge

The announcement by the English Steel Corporation, Ltd., that the Darlington Forge would recommence work early in 1936 was accompanied by the statement that the plant and equipment would be modernised throughout.

The work of reconditioning the buildings and installing new plant has moved rapidly since that announcement was made, and we are now informed that, following a preliminary run in several of the departments, the Works have definitely started production. The first cast of steel has been tapped in the melting department, which department will at once go into full production. It will provide steel for the forge and foundry, for use in the manufacture of the high-quality forgings and castings so intimately associated with this firm in the minds of the marine, electrical and general engineering industries, and in addition, for carbon and alloy-steel ingots up to 100 tons in weight.

A large anvil block dispatched from the works of English Steel Corporation, Ltd. The dimensions of this casting are 10 ft. 2 in. × 9 ft. 2 in. × 6 ft. 1 in. high, and the finished weight over 100 tons.

It has been decided for the time being not to reopen the light foundry or to manufacture phosphor and manganese bronze castings, but to confine the foundry work to steel castings of from 15 cwt. to 100 tons in weight. Special mention should be made of the new heat-treatment plant which is being erected to enable the all-important process of heat-treatment to be carried out more efficiently.

Skilled men who left the Darlington Forge when it closed down in 1932, are all returning. Their experience will be valuable, as they have a knowledge of customers particular requirements. In the past, these Works built up quite a reputation for ship repairs and breakdown work, and we understand their present equipment enables them to give even closer attention to such work.

The sum involved in reconditioning and reopening these well-known Works is very considerable, but it is felt that the more efficient and additional capacity will be of great assistance to the industry, and of special interest to North East Coast shipbuilders and engineering firms. The Company will continue to install modern equipment, including new machine tools, to meet the developments in technique which have taken place since the Works closed down in 1932.

High-strength Metals Symposium features at A.S.T.M. Meeting

CONSIDERABLE interest was evoked at the 1936 A.S.T.M. Regional Meeting, held in Pittsburgh on March 4, by the five technical papers comprising the Symposium on High-Strength Constructional Metals which was the technical feature of the meeting. Two sessions, morning and afternoon, were devoted to the papers and discussion. Discussion of the papers was most interesting, especially in the afternoon session, when the two papers on steels were given. The papers presented were "Alloys of Aluminium and Magnesium," by Mr. E. H. Dix, jnr., and Mr. J. J. Bowman; "Alloys of Copper," by Mr. C. H. Davis; "Alloys of Nickel," by Mr. G. F. Gaiger; "Carbon and Low-Alloy Steels," by Mr. E. F. Cone; and "Corrosion-Resisting Steels," by Mr. E. E. Thum.

The symposium was developed by a special programme committee under the chairmanship of Mr. Jerome Strauss. Extensive work on the part of the authors was evidenced in the great amount of valuable data and information presented. In the opinion of leading technologists at the meeting, the published symposium will serve a most useful purpose in bringing together in one convenient place the latest information on the physical and metallurgical properties, etc., of the constructional and higher strength alloys developed in recent years.

The question of corrosion came up for spirited discussion in the afternoon session, and it was evident that engineers—and designers especially—would welcome authoritative information on the corrosion-resistant properties of some of the newer constructional metals.

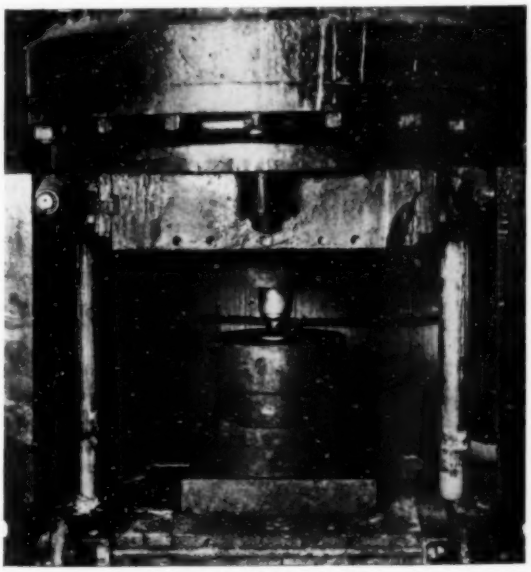
Recent Developments in Materials, Tools and Equipment

Cold-hobbing Die Steel

THE hobbing process of mould production for the plastic industry has become prominent by virtue of the ever-increasing demands made upon it. This increased demand has meant progress with the inevitable reversion from the old and laborious methods of die manufacture, to the comparatively new, direct oil hardening steel for the cold-hobbing process, which has only been made possible by the gradual development of suitable steels and alloys. The ultimate result of this, of course, has been higher output, lower costs, and greater excellence of production.

By courtesy of C. Joselin & Co.
Cold hobbed dies.

The fundamental process is the preparation of the master hob, and the suitability of steels for this, has been, and still is, the subject of careful and detailed investigation. The outcome of much research work is embodied in "Solar" Eclipse a specially alloyed steel, with all the desirable properties inherent in it. The tremendously high stresses involved in the process, together with other necessitities are more than met in this steel. First of all, it is necessary to have a steel which offers no difficulty to the machining and engraving of the intricate designs often required. To ensure this ease of machining, great care must be paid to the chemical composition, the chemical specifications



Press producing the dies.

must be strictly maintained, and to the mechanical work throughout manufacture. It must also be borne in mind, that maximum softness as registered by say, the Brinell scale, is not entirely the best criterion of efficiency in machining. The heat-treatment of this type of steel calls for little more than the usual care, hardening, as it does, at a comparatively low temperature, therefore, greatly minimising the possibility of decarburisation and distortion.

The mild alloy steel "Eclipse 75" for cold hobbing was evolved after lengthy research to produce a steel for multiple impression work that would harden direct in oil, as against the old practice of case-hardening mild steel. It will be readily appreciated that a direct quenched mould will, with its much greater tensile strength, offer greater resistance to abrasion and compression.

The impressions being produced cold from a solid blank under hydraulic pressure, it is necessary that the steel should flow well, and the resultant mould is left in a highly burnished or bright condition. Pack hardening should be used to ensure the surfaces do not become decarbonised, thereby helping very appreciably the ultimate high degree of polish that is so necessary to the plastic industry.

Electric Furnace Brazing

In the sphere of bright annealing the most important progress concerns the improvement in the technique of generating a suitable furnace atmosphere. Practically every metal can now be bright annealed, the necessary atmosphere being obtainable on a commercial scale and at genuinely reasonable rates. The progress made in

Some typical parts which have been brazed in a special electric furnace.

bright-annealing technique has led to the application of controlled atmosphere furnaces to the fabrication of ferrous and non-ferrous parts by brazing with copper, brass or other alloys. Improvements in bright-annealing furnace design has now made this process commercially practicable on the scale required in mass-production practice.

Furnaces of this kind have been developed by Messrs. Birmingham Electric Furnaces, Ltd. Generally they are of the belt-conveyer type and, since the temperature required to melt copper is of the order of 1,150° C., it is obvious that the design calls for special care. Several of these furnaces, however, are in daily use, having proved themselves not only strikingly economical as compared with assembly methods—such as torch brazing, riveting, welding, etc.—but also entirely reliable.

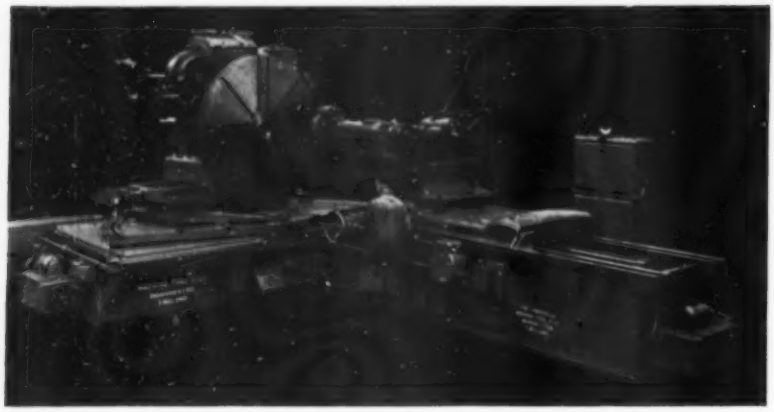
Copper brazing by this method has the advantage of enabling a given component to be constructed from an

assembly of cheap pressings and similar parts. Not only is the manufacturing cost decreased by the simpler method made possible, but the actual weight of material is generally reduced, labour for fabrication almost entirely eliminated and the strength of the finished article very high indeed. Copper, it may be noted, can give a tensile strength even exceeding 25 tons per sq. in. between two steel parts. The results which are being achieved on a normal production basis show that electric furnace brazing opens up an entirely new manufacturing technique for many types of components and, with a proper consideration of the assembly, effects an over-all simplification and cheapening of the product, which corresponds to a substantial saving in production cost. A further advantage of this new manufacturing process is the cleanliness of the operations which are conducive to the greater comfort of the assembling operators.

In electric furnace brazing—some sample products of which are shown in the accompanying illustration—all stresses in the material are automatically relieved while its surface is free from oxide. In general, therefore, this kind of furnace gives a better and at the same time a cheaper product than previous methods used for many types of component.

New Universal Grinding Machine

An entirely new universal grinding machine has recently been constructed by the Churchill Machine Tool Co., Ltd. It was designed in collaboration with British Timken, Ltd., for use in their works. The machine, which is shown in the accompanying illustration, is capable of grinding internal and external diameters, both parallel and taper. It is also



New universal grinding machine.

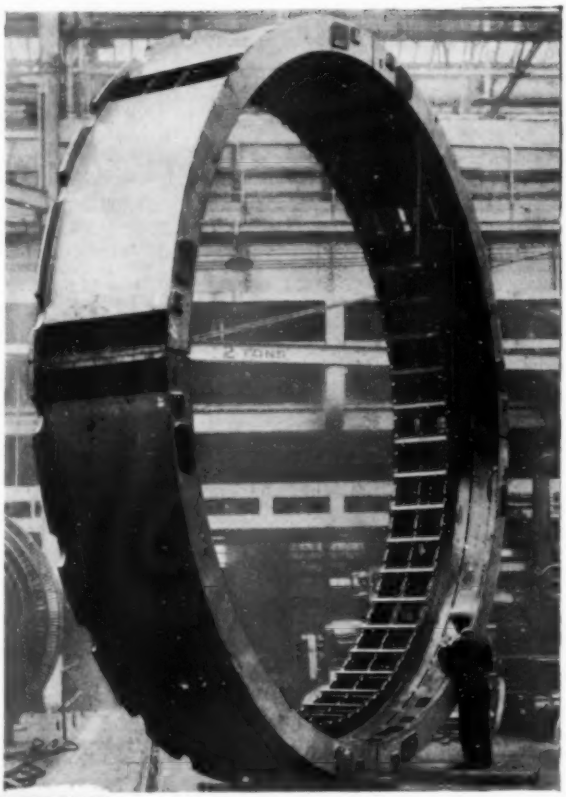
arranged to grind end faces and spherical and curved surfaces, such as are necessary for the tracks of ball races. The machine is fully universal and hydraulically operated, with a capacity to grind components up to 7 ft. in diameter and 30 in. long. By means of a modification, provision exists for the grinding of pieces of even greater diameter. The various motions of the machine are driven by seven electric motors, varying from 35 h.p. to ½ h.p. Its total nett weight is approximately 45 tons.

The development of this new grinder has been brought about by the steadily increasing demand for the heavy Timken large-diameter anti-friction bearings taking loads sometimes exceeding 5,000,000 lb., and necessitating fine limits in precision.

Large Welded-frame Alternators

Two 24,000 kVA. vertical waterwheel alternators are being manufactured by the Metropolitan-Vickers Electrical Company for the Arapuni power station of New Zealand.

The alternators are rated at 24,000 kVA., 11,000 volts, three-phase, 50-cycles, 214 r.p.m., and are probably the largest electrical machines of which construction has yet



The yoke for a large alternator which is entirely of welded steel construction.

been undertaken by British manufacturers. The yoke, which is shown in the accompanying illustration, is just over 26 ft. in diameter and weighs nearly 18 tons. It is entirely of welded steel construction, consisting of a box frame of heavy sheet end and back plates with stiffening plates between. Round the inner periphery the frame is provided with welded axial ribs of dovetailed section for mounting the core laminations. The design of the frame and the scheme of welding operations were carefully planned to avoid distortion and to reduce subsequent machining to a minimum.

Because of the necessity of dividing such a large stator for shipping, the frame was made in quarters. The segments for the end plates were flame-cut from steel plate 1¼ in. thick, two cutting torches carried on a radial arm being used to cut the inner and outer circles in one operation. In making joints with such heavy plates it was found economical to use ⅜ in. electrodes after initial use of small-diameter electrodes to reach into the bottom of the vee preparation. All the welding was, of course, carried out with M-V. welding equipment and electrodes. Coated electrodes were used throughout.

The assembly operations, both of the quarters and of the complete yoke, were carried out by means of a layout assembly diagram marked on level floor plates. The method used is to machine the fitting faces of the bolting plates and bolt them together before welding them to the section frames. A pair of plates so prepared is set up against the first frame, otherwise completed, and that frame is welded to its plate. With the pair of plates still bolted together, the second frame section is now moved into correct position and welded to its plate. The other sections are assembled similarly. As will be realised, this simple arrangement ensures accurate assembly quite irrespective of the plane in which the joint has been set up.

Business Notes and News

Andrew Carnegie Gold Medal

The Council of the Iron and Steel Institute have decided to award the Andrew Carnegie Gold Medal, for 1935, to Dr. D. F. Marshall, of Sheffield, for his paper on "Further Developments of the External Heat Loss of Blast-Furnaces," which was published in the Journal of the Iron and Steel Institute for 1935, vol. No. 1. It is noteworthy that in 1933, the Williams Prize was awarded jointly to Dr. Marshall for his paper on "The External Heat Loss of a Blast-Furnace," in which the author presented the results of a research of which his Carnegie report recorded the continuation.

British Separators Required by Alfa-Laval Co.

Messrs. Vickers, Ltd., advise us that the Alfa-Laval Co., Ltd., of Brentford, who are the sole agents of Aktiebolaget Separator of Stockholm for Great Britain and Ireland for the manufacture and sale of the well-known De Laval Separators, have now acquired from Cooke, Troughton and Simms, Ltd. the business of British Separators, Ltd. The Separators sold by British Separators, Ltd., are known throughout the trade as "Vickcen" Separators, and have been installed in the *Queen Mary*. The purchasers are making adequate arrangements for the servicing of "Vickcen" Separators and the supply of spare parts.

All future inquiries for "Vickcen" Separators, Filters and parts should be addressed to British Separators, Ltd., at their new address Great West Road, Brentford, Middlesex.

South African Orders for Britain

Industrialists in Britain are realising, in an increasing easure, the importance to them of the South African market, which absorbed more of Great Britain's exports last year than any other country in the world. A concrete example of the value of the South African market is afforded by three orders placed by the South African Government recently. The first was one for two steam tugs for the Harbours administration. This went to Scotland, the contract price being £197,000, and another for a suction dredger costing £140,000, was also obtained by Scotland. The third to be placed is for rails and fishplates to a total amount of £461,000. Of this £106,000 went to Canada and £354,000 to the United Kingdom, distributed amongst firms in Barrow, Glasgow, Manchester and Workington.

Conference on Oxygen Blast in the Donetz Basin

A conference was recently held at the Kirov Plant in Makeyevka (the Donetz Basin) on the question of utilising oxygen blast in blast furnaces. The conference was attended by Academician N. A. Pavlov, well-known Soviet metallurgists and representatives of scientific research institutes.

The practical application of the oxygen blast would enable the Makeyevka plant to obtain a co-efficient of from 0·3 to 0.4 in the utilisation of its blast furnaces, was the opinion of the director of the Kirov Plant. He said it would treble the production of iron in the plant and obviate the need to build the three new blast furnaces planned.

Academician Pavlov stressed the great importance of oxygen blast for improving the technological process of metallurgical production and increasing the output of iron, and Academician Baikov expressed the view that the oxygen blast would open a new page in the history of metallurgy.

WANTED

METALLURGIST with long experience in steel foundry laboratories and metallographical experience. Must know analytical processes for following elements: C, Mn, Si, P, S, Cu, Al, As, N, O, also determination of impurities such as Al_2O_3, CaO, MnO, Fe_2O_3; further, must be able to determine alloying components in steel such as Ni, Co, Cr, V, W, Mo, Ti. Knowledge German essential. Good prospects.—Applications to Box No. 425 c/o Kennedy Press Ltd., 21, Albion Street, Gaythorn, Manchester 1.

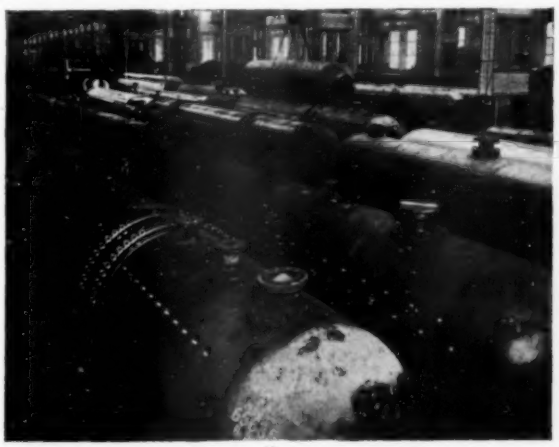
Staff Pensions

It is gratifying to note that many enterprising firms have taken the initiative in formulating their own pension schemes for the benefit of their employees, the pensions to commence at the age of 60, whether the employee retires or carries on with his job. A recent addition to these select few is the firm of David Brown and Sons (Hudd.), Ltd., Hudderfield. A contributory scheme has been introduced which provides benefit for its male weekly and monthly rated employees over 21 years of age who have completed three months continuous service.

In addition to paying the balance of the cost of every employee's contribution, the Company bears the whole cost of past service pensions, and also the whole cost of the cover for the insurance of all pension scheme contributors. This means that in generously appreciating the past service of its employees, the Company will provide, at no cost to the men, a pension at half rate in respect of each completed year of service after the age of 21, up to a maximum of 10 years. This consideration is wholeheartedly appreciated by the staff and it is not surprising that practically every eligible employee made application almost immediately.

Hollow Forged High-Pressure Vessels

The complete modernisation of the melting house, heat-treatment and machine shops has enabled the English Steel Corporation to cope with the ever-increasing demand for hollow forged high-pressure vessels in the manufacture of



which they are a leading authority in this country. The accompanying illustration gives some idea of the volume of this class of work at present passing through the machine shops. The vessels are for orders received as far afield as India, Belgium, Australia and in this country from Birmingham, Leeds and other large cities.

Personal

We are informed that His Majesty, King Edward VIII has been graciously pleased to grant his Patronage to the Iron and Steel Institute.

It may be recalled that the Institute was similarly honoured by the late King George V and by King Edward VII before him, both of whom had previously shown their interest in the Institute's activities by consenting to accept Honorary Membership. His Majesty King Edward VIII was also an Honorary Member until his accession to the Throne.

Dr. Skerl, well known an as authority on sands, is taking up his residence at "Plowlands," Marshalwick Lane, St. Albans (Telephone 1975), from where he will conduct an independant consulting practice. This is entirely apart from the duties relating to his recent appointment with Messrs Sternol Ltd., where he is in charge of the foundry department dealing with the manufacture and sale of core binders. We are pleased to learn, therefore, that his services will still be availabie to the foundry trade.

MARKET PRICES

ALUMINIUM.

98/99% Purity	£100	0	0

ANTIMONY.

English	£73	0	0
Chinese	60	0	0
Crude	31	10	0

BRASS.

Solid Drawn Tubes	lb.	9¾d.
Brazed Tubes	„	11¾d.
Rods Drawn	„	8¾d.
Wire	„	7¾d.
*Extruded Brass Bars	„	4¼d.

COPPER.

Standard Cash	£36	12	6
Electrolytic	40	15	0
Best Selected	39	15	0
Tough	39	5	0
Sheets	68	0	0
Wire Bars	41	0	0
Ingot Bars	41	0	0
Solid Drawn Tubes	lb.	10¼d.	
Brazed Tubes	„	10½d.	

FERRO ALLOYS.

‡Tungsten Metal Powder	lb.	0	3	3
‡Ferro Tungsten	„	0	3	0
Ferro Chrome, 60-70% Chr. Basis 60% Chr. 2-ton lots or up.				
NOMINAL 2–4% Carbon, scale 11/- per unit	ton	29	15	0
NOMINAL 4–6% Carbon, scale 7/- per unit	„	22	7	6
NOMINAL 6–8% Carbon, scale 7/- per unit	„	21	12	0
NOMINAL 8–10% Carbon, scale 7/- per unit	„	21	12	0
§Ferro Chrome, Specially Refined, broken in small pieces for Crucible Steelwork. Quantities of 1 ton or over. Basis 60% Ch. Guar. max. 2% Carbon, scale 11/0 per unit	„	33	10	0
Guar. max. 1% Carbon, scale 12/6 per unit	„	36	5	0
§Guar. max. 0·7% Carbon, scale 12/6 per unit	„	37	5	0
‡Manganese Metal 97–98% Mn.	lb.	0	1	2
‡Metallic Chromium	„	0	2	5
§ Ferro-Vanadium 25–50%	„	0	12	8
§ Spiegel, 18–20%	ton	7	10	0
Ferro Silicon—				
Basis 10%, scale 3/- per unit	ton	6	5	0
20/30% basis 25%, scale 3/6 per unit	„	9	0	0
45/50% basis 45%, scale 5/- per unit	„	12	5	0
70/80% basis 75%, scale 7/- per unit	„	17	17	6
90/95% basis 90%, scale 10/- per unit	„	28	17	6
§ Silico Manganese 65/75% Mn., basis 65% Mn.	„	12	17	6
§ Ferro-Carbon Titanium, 15/18% Ti	lb.	0	0	4½
Ferro Phosphorus, 20–25%	ton	20	0	0
§ Ferro-Molybdenum, Molyte	lb.	0	4	6
§ Calcium Molybdate	„	0	4	2

FUELS.

Foundry Coke—				
S. Wales	—	1	6	6
Scotland	—	1	10	0
Durham	1 3 6 to	1	4	0
Furnace Coke—				
Scotland	—	1	5	0
S. Wales	—	1	0	6
Durham	—	1	1	0

GUN METAL.

*Admiralty Gunmetal Ingots (88 : 10 : 2)	£60	10	0
*Commercial Ingots	44	0	0
*Gunmetal Bars, Tank brand, 1 in. dia. and upwards	lb.	0	0 9
*Cored Bars	„	0	0 11

LEAD.

Soft Foreign	£16	2	6
English	18	5	0

MANUFACTURED IRON.

Scotland—			
Crown Bars, Best	£10	5	0
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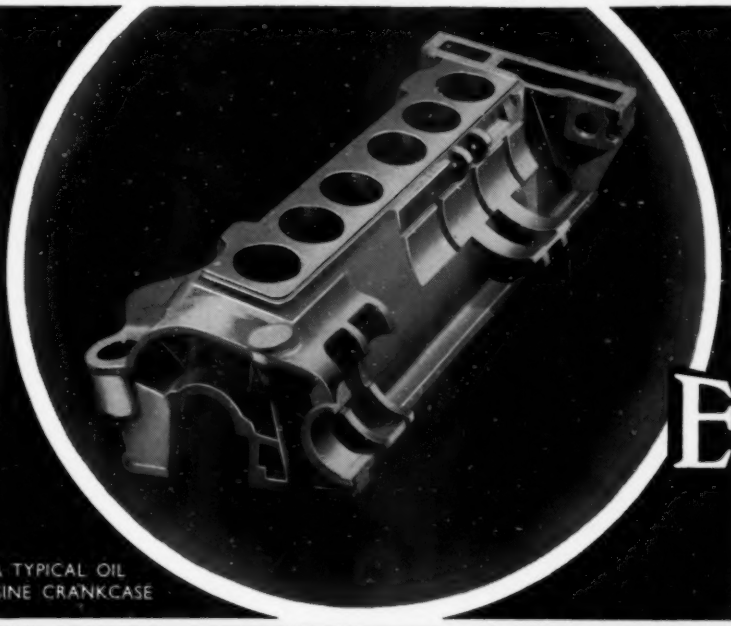

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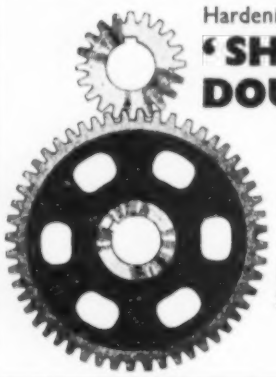

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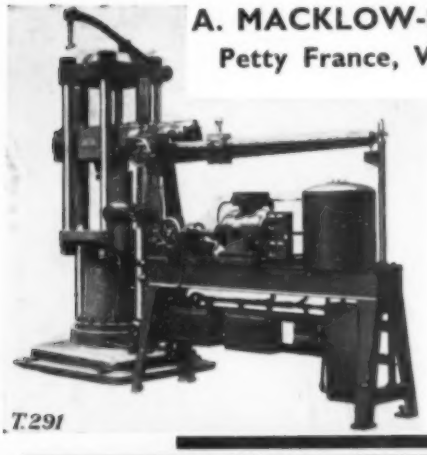

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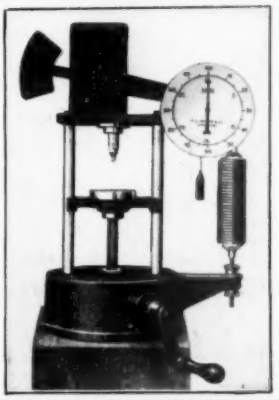

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